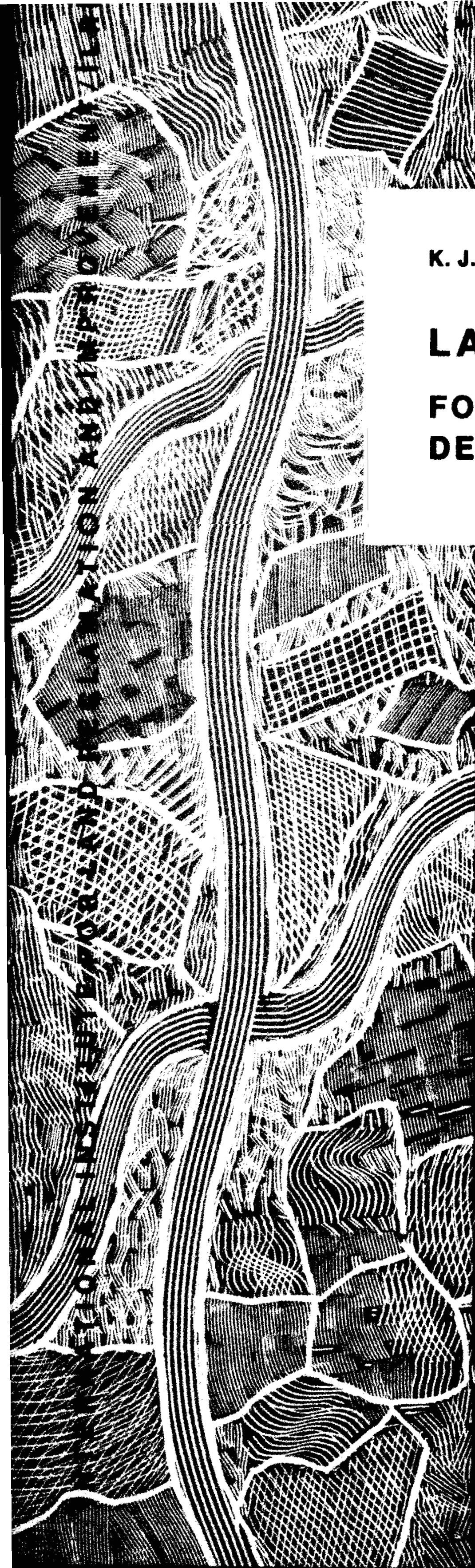

K. J. BEEK

LAND EVALUATION

FOR AGRICULTURAL DEVELOPMENT

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FOR AGRICULTURAL DEVELOPMENT

Some explorations of land-use systems analysis
with particular reference to Latin America

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FOREWORD

During the last three decades great progress has been made in identifying and characterizing the world's major soils. The use being made of resource data for development projects, however, has been lagging far behind. The reasons for this situation are that these data are often presented in a form which is not readily accessible to the potential user, or that land use planners find it more convenient to handle economic parameters without taking physical variables into account.

The increasing and competitive demand for land, both for agricultural production and for other purposes, requires that decisions be made on the most beneficial use of limited land resources, whilst at the same time conserving these resources for the future. It is a function of land evaluation to bring about an understanding of the relationships between the conditions of the land and the uses to which it is put, and to present planners with comparisons and options of promising alternatives.

By 1970 many countries had developed their own systems of land evaluation. Some were very general in scope and were limited to assessing areas of land suitable for cultivation, forestry or grassland. Other systems were concerned with single forms of land use, e.g. irrigated agriculture. There was a clear need for international standardization and especially for the development of a classification which allowed a comparative evaluation of the different uses that can be made of the same land.

The general principles which are fundamental to this approach are that land is evaluated with respect to specific types of land use and in terms relevant to the physical, economic and social conditions of the area concerned. Through an international cooperative effort, FAO developed a framework for land evaluation by which land can be assessed, with regard to its soil and climatic conditions, in terms of requirements for successful growth of different crops, or for alternative types of land use.

Since the early days Dr. Klaas Jan Beek has been closely associated with this effort. The field work which he has been carrying out with FAO since 1963 contributed considerably towards establishing relationships between land qualities and crop requirements. Dr. Beek was instrumental in defining different types of land utilization which express the use of land in terms of produce, labour, capital, management, technology and scale of operations. The principal objective of his book is to strengthen the foundation of land evaluation by consolidating the 'land utilization type' concept. The rapidly increasing number of land use systems and the great variety of the related land requirements and management alternatives, called indeed for an in-depth study of the land utilization type itself, including the application of statistical methods and modelling.

Dr. Beek's intensive work in Latin America has led towards new methods of land evaluation being introduced in that region. The synthesis presented in this book should promote the further application of a methodology which, through an inter-disciplinary approach, provides a basis for land use planning decisions that take into account the qualities and constraints of the physical and socio-economic environment.

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Director
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LAND EVALUATION

Increases in the demand for agricultural produce and for space to meet non-agricultural needs are provoking rapid changes in the use of land. These changes have stimulated a critical examination of our methods of looking at land. Most useful is a land evaluation that predicts the inputs, outputs, and other favourable as well as adverse effects resulting from specified uses of the land that is being evaluated (Chapter 1).

LAND UTILIZATION TYPES

Thus, relevant uses need to be identified at an early stage (Chapter 2). This has not always been satisfactory. To help in land evaluation, the concept 'land utilization type' (LUT) has been introduced. This is defined as a specific way, actual or alternative, of using the land, described in terms of produce, labour, capital, management, technology and scale of operations. The principal objective of this thesis is to strengthen the philosophical base of land evaluation by explaining the LUT concept. Many similarities exist between this concept in land evaluation and other land-use defining concepts such as production and farming systems. Due to the complicated interactions that occur between their many constituent parts, the analysis of farming systems cannot fully account for the variation in physical land conditions. Land evaluation contributes to solving this problem by making preliminary and partial analyses of the variability of the land and of its influence on the performance of present and alternative land uses. To this end, land use is arbitrarily subdivided into two elements: the land (LU), mostly described by land evaluators in terms of land (mapping) units, and the use (LUT). Thus it should be possible to predict the performance of different LU, LUT combinations, called 'land use systems' (LUS) in this report. Such a 'land-use systems approach' should permit easy extrapolation of the land evaluation results to farming systems research and land use planning.

LAND REQUIREMENTS AND LAND QUALITIES

In agronomy the term 'requirement' is commonly used when referring to the specific land conditions required for the successful growth of a crop or the functioning of an agricultural implement, e.g. the water requirements of wheat or the soil workability requirements of a tractor-driven plough. These land requirements (LR) are the most fundamental aspects of the land utilization types for purposes of land evaluation (Chapter 3). A very critical aspect of land evaluation is the availability of information

about these LRs, especially in developing countries. Most useful are the descriptions of LR expressed in terms of relationships between different levels of specified land conditions and the corresponding levels of output, e.g. a table or graph that relates different levels of soil salinity with yield.

The land requirements of a LUT determine to a great extent which land resources data need to be studied and in how much detail. Early identification of LUTs and their land requirements may considerably reduce the cost and duration of the land resource studies by focussing attention on those land characteristics that may not wholly meet these requirements. In any event, land resource studies result in an enormous amount of data about soil, climate, hydrology etc. But, because of the way data are collected according to the academic discipline of the researcher, important relations and interactions between different land attributes are often overlooked, particularly those between climate and soil. To synthesize the overwhelming volume of data into a more comprehensible form, the construction of simple functional models of the physical environment (LU) is proposed, based on the concept of land qualities. A land quality is a component of the land which acts as a separate factor on the land-use performance. The following broad types of land qualities have been distinguished:

- ecological qualities; e.g. available water, length of growing season;
- management qualities; e.g. the possibility of using specified types of implements or transportation;
- conservation qualities; they represent the land's unique capacities to maintain the status of the land qualities, in particular the productive capacity;
- improvement qualities; land units differ in behaviour when certain physical inputs are applied for their improvement: they have a different 'input application efficiency', e.g. in their response to fertilizers or irrigation water.

There is still much to be achieved in the quantitative measurement of land qualities. They are usually ranked on an ordinal scale: high-medium-low-very low. Statistical methods, such as multiple regression and principal component analysis, are also used as a means of rating land qualities, e.g. soil fertility or soil erosion susceptibility. The success of these statistical methods for describing land qualities seems to be attributable to the small number of factors taken into account. The prospects of using mathematical and analog models for characterizing and simulating dynamic land qualities influenced by the weather, e.g. the soil workability, oxygen contained in the soil, soil nitrogen, are very important. The timing of land-use activities and processes of the LUT – the cropping calender – affects the way in which the time intervals need to be chosen for measuring and simulating dynamic land qualities and component properties.

Land evaluation should be able to predict the impact of land use proposals not only for single land (mapping) units but also for combinations of land units and for the physical environment as a whole. Also, interactions occurring between different land uses operating on different land units should be foreseen. For this purpose, a distinction is proposed between internal land qualities of individual land units and overall land qualities of major landscape elements, internal land requirements of individual land utilization types and overall land requirements encompassing the sum of individual land requirements made by the different land utilization types that operate simultaneously.

APPROACHES TO LAND EVALUATION, LATIN AMERICA

In Chapter 4 the different approaches to land evaluation are presented. At the highest level, a distinction is made between general purpose and specific purpose land evaluation. General purpose land evaluation represents a standardized approach for all lands to evaluate their capability to support a generally defined land use. The best known example is the USDA Land Capability System. Specific purpose land evaluation represents a pragmatic approach: not only the land but also the use possibilities (LUT) are explicitly studied. The use (LUT) becomes as much a determinant of land suitability as the land itself. Many land suitability classifications for specific crops belong to this category.

To compare the performances of different LU-LUT combinations, not only an analysis of the physical factors is needed (physical land evaluation), but also a socio-economic analysis. The approach to land evaluation that includes socio-economic analysis has been named 'integral land evaluation'.

Application of the proposed concepts and procedures of land evaluation requires close contact with the farmer: his operations need to be observed, and his achievements, attitudes, and expectations taken into account. During field surveys, one should always be on the look-out for potentially constraining land qualities. Observation of present land use and discussions with farmers will improve the correspondence between the real land conditions and their descriptive models in terms of qualities and properties.

To illustrate the above concepts and procedures in land evaluation, methods from Venezuela, Nicaragua, Mexico, Brazil, and Chile are described. In Latin America land evaluation is relied on as a fundamental source of information for agricultural development. Land evaluation methods that evolved in other countries, especially the USDA Land Capability System, have not been rigidly followed. New systems are being developed to suit local needs. The willingness of national scientists to abandon established methods of land capability classification is encouraging the introduction of new approaches that pay more attention to the biological, technical, and socio-economic aspects of land use, and in particular to the farmer himself. In such specific-purpose land evaluations, the dynamic aspects of land and land use can no longer be ignored; this is making land evaluation more complex, but not insurmountably so, given today's data-handling techniques. This idea is elaborated in Chapter 5, where the possibilities for using systems analysis are explored.

LAND-USE SYSTEMS ANALYSIS

Land-use systems analysis in land evaluation must be understood as 'simulation', defined by De Wit and Goudriaan (1974) as the building of a dynamic model and the study of its behaviour. The land-use model only includes that part of reality that is needed to answer the questions asked: to predict inputs (I), outputs (Y) and changes in the values of land qualities (LQ), on-site or off-site, that would arise if a particular LU were to be combined with a specific LUT.

To be able to provide this information the relation structure of the land-use system must be known. This consists of three fundamental relations:

$$Y = F(LQ); \quad LQ = F(I); \quad Y = F(I)$$

These relations are interrelated; one relation can be derived from the two others through the elimination of one variable, usually LQ. A graphical method of co-axial analysis is shown for expressing the I-LQY relations.

A further simplification is the tabular presentation of the relation structure of a land-use system, presenting only a few input-land quality-output combinations. Two multiple-entry tables are proposed: the land quality table (Table 5.4A) expressing the input-land quality relations for land units(LU) with different land improvement qualities, and the output table (Table 5.4B) expressing land quality-output relations for land utilization types (LUT) with different land requirements. Combination of the two tables permits the identification of several alternative input-land quality-output combinations for each LU-LUT combination.

A distinction is made between descriptive and prescriptive land-use systems analysis. During the descriptive analysis, physical inputs for ameliorating constraining land qualities, their management and conservation, are compared with their effects on the land qualities and the outputs: 'descriptive input-output analysis'. This information is needed for the next step, when the suitability of a particular land unit (LU) for combination with a particular land utilization type (LUT) is classified: 'prescriptive land suitability classification'. During this second step, for each LUT-LU combination, the input-land quality-output combination is selected which places the land unit in the highest possible land suitability class: a kind of optimization process.

CONCLUSION

The use of simulation models of specific land use processes and mechanisms holds much promise for land-use systems analysis and is therefore likely to increase, particularly in situations where the physical and/or socio-economic conditions seriously limit a satisfactory matching between land qualities and land requirements.

Such models will probably relate primarily to specific partial land-use problems, e.g.

drainage, soil tillage, the behaviour of nitrogen or chemical fertilizers, and to potential yield. In the immediate future the use of mathematical models solely for simulating all input-ouput relations influencing the performance of a land use system will probably remain too complex to satisfy practical land evaluation entirely. Thus land evaluation must compromise between scientific ideals and the limitations posed by data availability, data reliability, and the possibilities for data handling.

Meanwhile land resources inventories should aim increasingly towards the collection of data that explicitly characterize the fundamental environmental regimes (i.e. land qualities) influencing the physiological and agricultural mechanisms and processes, to improve the possibilities for land-use simulation and the prediction of land-use performance.

RESUMEN

EVALUACION DE TIERRAS PARA EL DESARROLLO AGRICOLA

EVALUACION DE TIERRAS

La demanda creciente de productos agrícolas y la necesidad de poder disponer de tierras para fines que no sean agrícolas, causan grandes modificaciones en el uso de la tierra. Esto ha llevado a una consideración crítica de nuestros métodos para la evaluación de tierras. Los métodos más útiles son los que permiten pronosticar acerca de los insumos, los resultados y otras consecuencias favorables o desfavorables de un cierto uso de la tierra en cuestión (Capítulo 1).

TIPOS DE USO DE LA TIERRA

Es necesario por lo tanto, que en un principio se identifiquen los usos más relevantes de la tierra. Podrá ser el uso actual, pero en general se aplica la evaluación de tierras en el cuadro de un plan de desarrollo, en el cual las modificaciones del uso de la tierra juegan justamente un papel muy importante (Capítulo 2). Los métodos de evaluación de tierras que utilizan los especialistas de suelos, más conocidos como la clasificación de tierras o la interpretación de mapas edafológicos, fallan en cuanto a la atención prestada al uso de la tierra y al hombre que la utiliza. Para ayudar la evaluación de tierras, se introdujo el concepto 'tipo de uso de la tierra' (Land Utilization Type, LUT) durante una consulta de expertos de la FAO celebrada en Wageningen, Holanda, en 1972. Antes también se había aplicado este concepto en una nueva metodología para la interpretación de mapas edafológicos en el Brasil. Un tipo de uso de la tierra (LUT) es una manera específica de utilizar la tierra, actual o alternativo, y está descripta en términos de producto (cultivo), empleo, capital, manejo, tecnología y escala de operaciones.

Esta tésis intenta mejorar la metodología de la evaluación de tierras, dando una explicación más detenida sobre el lugar que le pertenece al uso de la tierra y sobre todo al usuario mismo, dentro de dicha metodología. El babel de lenguas de la literatura internacional tratándose de conceptos como 'sistema de producción', 'sistemas agrícolas' y 'uso de la tierra' será aún más grande si añadimos el concepto LUT de la evaluación de tierras. Sin embargo, después de haber explicado los conceptos más similares, se debe constatar que para el llamada 'farming-system research', hoy día resulta muy difícil de tomar en cuenta suficientemente las características variables de la tierra. La dificultad surge por la estructura de relaciones sumamente complicada del sistema agrícola, que está compuesto de una cantidad muy grande de variables y parámetros físicos, sociales y económicos, de los cuales algunos son además variables en el tiempo. Para aliviar estos problemas, los que efectuen la evaluación de tierras, tendrán que hacer un análisis provisional del uso de la tierra, muy simplificado, que se refiere solamente del estudio de la variabilidad de la tierra y su influencia en los resultados del sistema de este uso. Por eso es deseable de dividir el uso de la tierra en dos elementos: el 'uso' y la 'tierra'. Para la 'tierra' se utiliza normalmente en la evaluación de tierras la palabra 'unidad (de mapeo) de tierra' o 'land (mapping) unit', LU. Y con el 'uso' se entiende aquí el concepto arriba mencionado ya de 'tipo de uso de la tierra', LUT. En cuanto LU y LUT sean conocidos se trata de pronosticar el comportamiento de la diferentes combinaciones de LU y LUT. En este informe llamaremos tales combinaciones sistemas de uso de la tierra (land-use systems, LUS). Un método por sistemas de uso de la tierra procurará que los resultados de la evaluación de tierras sean los más útiles posible para el farming-system research y para el planeamiento del uso de la tierra, que en su turno tendrán que contribuir mucho al desarrollo de la populación rural en las regiones tropicales y subtropicales.

REQUERIMIENTOS DE TIERRA Y CUALIDADES DE LA TIERRA

En la literatura internacional el término 'requirement', traducido aquí por 'requerimiento', se utiliza muchas veces para indicar qué es lo que se le exige a la tierra en cuanto al crecimiento de las plantas o al uso de cierto tipo de maquinaria: el requerimiento de agua y el requerimiento de cultivo (Capítulo 3). Estos requerimientos representan los aspectos más fundamentales del tipo de uso de la tierra (LUT), dentro de la evaluación de tierras. La disponibilidad de datos acerca de estos requerimientos de tierra es un factor restrictivo para la evaluación de tierras, sobre todo en los países en desarrollo. Las más útiles son las descripciones de los requerimientos de tierra expresadas como relaciones entre niveles especificados de una cierta característica de la tierra y el resultado relacionado con dicho nivel del sistema de uso de la tierra en cuestión. Por ejemplo un cuadro o un gráfico que indica la relación entre los diferentes niveles de salinidad de la tierra y los rendimientos que se esperan de ciertos cultivos. Los requerimientos del tipo de uso (LUT) fijan en gran medida que propiedades de la tierra tendrán que estudiarse y a que nivel de detalle esto tendrá que efectuarse. Una identificación de los LUT y de los requerimientos de tierra, al iniciar el estudio, podrán limitar considerablemente los gastos y la duración de los estudios de la tierra, ya que nos podramos fijar en esas caracteristicas de la tierra que no estén de acuerdo con los requerimientos de los LUT. Sin embargo se producen, durante el levantamiento y la experimentación, grandes cantidades de datos sobre la tierra, referente al suelo, clima, vegetación, hidrología etc. Por desgracia se descuidan frecuentemente por la manera de juntar los datos según la especialización del investigador, relaciones e interacciones importantes entre los diferentes atributos de la tierra, y sobre todo entre suelo y clima. Por eso pasa con frecuencia que no se presta suficiente atención a las características dinámicas del suelo en la evaluación de la tierra. Para llegar a una síntesis de la cantidad impresionante de datos sueltos, se pasó ya en el año 1960, en el Brasil, a la construcción de modelos simples y funcionales del medioambiente físico (las unidades de mapeo), haciendo uso de 'cualidades de la tierra'.

Una cualidad de la tierra es un elemento de la tierra, con una influencia independiente sobre los resultados del sistema de uso. Se podrán distinguir las siguientes clases de cualidades de la tierra:

- cualidades ecológicas, como p.e. la cantidad de agua disponible para la planta; la duración del período de crecimiento;
- cualidades de manejo, p.e. las posibilidades para el uso de ciertos tipos de maquinaria y medios de transporte;
- cualidades de conservación. Estas son las facultades de la tierra para poder conservar el nivel original de sus diferentes cualidades, como también su capacidad productiva;
- cualidades de mejoramiento; unidades de tierra (LU) pueden diferenciar en su comportamiento, cuando se empleen ciertos insumos físicos para el mejoramiento de la tierra: tienen una eficiencia en la aplicación de insumos diferente, p.e. empleando fertilizantes químicos o agua de irrigación.

La etapa de la determinación cuantitativa de las cualidades de la tierra es aun incipiente. Casi siempre, también en Holanda y en el Brasil, se utiliza una escala de medición ordinaria: alto-medio-bajo-muy bajo. Métodos estadísticos como p.e. la regresión multiple y el análisis por componentes principales, también son aplicados por ejemplo en el terreno de la fertilidad y la erosión de suelos. El éxito de estos métodos estadísticos se debe, entre otras cosas, a la cantidad reducida de factores que se tienen en cuenta, por lo cual se trata todavía de relaciones funcionales entre las causas y los efectos. Por desgracia no se puede decir lo mismo de los métodos estadísticos empleados en la evaluación de tierra (los llamados métodos paramétricos se rechazan como tal).

Muy importantes son las perspectivas del uso de los modelos matemáticos y análogos para la descripción y la simulación de las cualidades de la tierra más dinámicas como el drenaje, el agua disponible para la planta, el nitrógeno en el suelo y la capacidad productiva (cosecha). Dependerá mucho del calendario de las diferentes actividades y procesos del uso de la tierra, de cómo se escojan los intervalos de tiempo y cuando se midan o se simulan las cualidades dinamicas de la tierra.
Al pronosticar las consecuencias de los diferentes usos de la tierra, la evaluación de tierras tendrá que tener en cuenta, de vez en cuando, que existen relaciones entre las diversas unidades de tierra (LU) formando parte de un paisaje mayor. Las interacciones entre diferentes usos de la tierra que se emplean en lugares que se encuentran a cierta distancia los unos de los otros, y los efectos de un cierto uso de la tierra, sobre las cualidades de la tierra en otras partes, deberán ser pronosticados. Por eso se hace una división entre las cualidades de tierra internas de las unidades de tierra individuales y las cualidades de tierra globales de los paisajes mayores y de los cuales forman parte las unidades de tierra. De la misma manera se puede hablar de los requerimientos de tierra internos de un cierto LUT y de los requerimientos de tierra globales, que representa el total de requerimientos de los diferentes LUT, a cuyas exigencias tendrá que satisfacer la tierra evaluada.

En el Capítulo 4 se ha intentado ordenar un poco los diferentes métodos de evaluación de tierras que hoy día se utilizan, sobre todo en America Latina. En el nivel más alto se hace una diferencia entre una evaluación de tierras para fines generales y una evaluación para fines específicos. La evaluación para fines generales representa un método estandardizado para toda clase de tierras, a fin de poder fijar su aptitud para un uso de la tierra general. El ejemplo más conocido es el Sistema de Capacidad de Uso de la USDA en los Estados Unidos. La evaluación de tierras para fines específicas representa un método pragmático: tanto la tierra como las posibilidades de uso (LUT) se someten a un estudio. El uso de la tierra (LUT) es tan determinante para la aptitud de la tierra como la tierra misma. Muchas clasificaciones de aptitud para cultivos individuales pertenecen a ello. Desafortunadamente, en muchos países en desarrollo se apliquen demasiadas veces todavía el Sistema de Capacidad de Uso, arriba mencionado, cuando en realidad se debería aplicar una evaluación de tierras que cuente más con el uso de la tierra específico y con los que trabajan esta tierra. Esta tésis pretende, por lo tanto, desarrollar, más que todo, la evaluación de tierras para fines específicos.

Para poder comparar los pronósticos del comportamiento de las diferentes combinaciones de LU y LUT, efectuados durante la evaluacion de tierras, un analisis de los factores fisicos resultará insuficiente (evaluación física de tierras). En estas circunstancias se necesitará también a veces un análisis socio-económico, que frecuentemente se efectua más tarde, pero que en evaluaciones de tierras muy detalladas se puede hacer al mismo tiempo que el análisis fisico.

La aplicación de los conceptos y métodos arriba mencionados, requiere una colaboración intima con los agricultores: sus actividades se observan, y se tienen en cuenta sus resultados, opiniones y esperanzas. Durante el levantamiento de las tierras, se deberán buscar continuamente esas cualidades de la tierra, que puedan limitar el uso. Observaciones del uso actual de la tierra y discusiones con los agricultores aumentarán en gran medida la semejanza entre la realidad y los modelos descriptivos de la tierra en términos de cualidades, sobre todo las cualidades dinámicas que el agricultor pueda constatar diariamente y sobre las cuales sus antepasados le hayan informado.

Como ilustración de los conceptos y métodos tratados hasta aquí, en el capítulo 4.3 se tratan unos métodos de evaluación de tierras de America Latina, donde el autor efectuó sus investigaciones en los años 1963 hasta 1974. Personalmente estaba más relacionado con la evaluación de tierras en el Brasil. También en otros países como Chile, Mexico y Venezuela participó en la realización de nuevos métodos de evaluación de tierras que prestan más atención al uso y al usuario de la tierra.

Durante el Seminario CIAT sobre la función de la ciencia del suelo en el desarrollo del Trópico Americano (Bornemisza and Alvarado, Eds, 1975) A. Colin Mc. Clung (experto de suelos) dijo las siguientes palabras notables: 'La ciencia del suelo es la disciplina agrícola más importante para el desarrollo del Trópico Americano. Ningún terreno de estudios tiene una importancia semejante...' Sea como sea, la evaluación de tierras que recibió poca atención durante este seminario, es sin duda ninguna una fuente de información fundamental para el desarrollo de la población rural de America Latina. Resúmenes de los métodos de evaluaciones de tierras aplicados en Venezuela, Nicaragua, Mexico, Brasil y Chile muestran que se estan desarrollando nuevos sistemas de evaluación de tierras que reemplazarán el sistema USDA y que se adaptarán más a las circunstancias locales. El interés que los expertos de suelos latinoamericanos han mostrado para la renovación es muy alentador para la introduccion de los métodos de evaluación de tierras que prestan más atención a los aspectos biológicos, técnicos y social-económicos de la tierra. Pero se deberá prestar mucho más atención, utilizando estos nuevos métodos, al clima y a los aspectos dinámicos de la tierra. Esto complicará más la evaluación de tierras, pero las técnicas actuales para el tratamiento matemático de datos, nos tendrán que ayudar. Para poder comprender en qué dirección tendrá que dirigirse la evaluación de tierras en los años que vienen, en el último Capítulo 5 se tratan más detenidamente las posibilidades para la aplicación del análisis por sistemas y de los modelos de simulación.

ANALISIS POR SISTEMAS DEL USO DE LA TIERRA

El análisis por sistemas del uso de la tierra en la evaluación de tierras tiene que considerarse como una forma de 'simulación', descrita por de Wit y Goudriaan (1974) como 'la construcción de un modelo dinámico y el estudio de su comportamiento'. Solo aquella parte de la realidad que estimamos necesaria para la contestación de las preguntas que nos han hecho se incluirá en el modelo de uso de la tierra. Estas preguntas son el pronóstico de los insumos, los resultados y las modificaciones de los niveles de las cualidades de la tierra, en el caso de que se combine una cierta unidad de tierra LU con un tipo específico de uso de la tierra LUT. Para poder contestar a estas preguntas, tenemos que conocer la estructura de relaciones del sistema de uso de la tierra, que está compuesto de tres relaciones fundamentales: Y = F(LQ); LQ = F(I); Y = F(I). Estas tres relaciones están también relacionades entre ellas, de modo que una relación se podrá deducir de las otras dos eliminando un variable, LQ casi siempre. En el Capítulo 5 se trata de un método de análisis coaxial para presentar gráficamente las relaciones I-LQ-Y. También se indica la utilidad de las funciones dis-contínuas, basándose en los resultados obtenidos por el Proyecto Internacional de la Evaluación de la Fertilidad del Suelo en North Carolina.

Una forma aún más simple para presentar la estructura de relaciones del sistema de uso de la tierra es la forma tabular, en el cual sólo se indican unos pocos niveles I-LQ-Y. Se recomiendan dos cuadros de entrada doble:

- el cuadro de cualidades de la tierra, que presenta las relaciones I-LQ para unidades de tierra (LU), con diferentes cualidades de mejoramiento, y
- el cuadro de resultados que presenta las relaciones LQ-Y para tipos de uso de la

tierra (LUT) con diferentes requerimientos de la tierra (LR).

Combinando estos dos cuadros, se obtiene la posibilidad de fijar las diferentes combinaciones de valores I-LQ-Y para cada combinación de LU y LUT. Se hace una diferencia entre el análisis por sistema descriptivo y prescriptivo. Al hacer el análisis descriptivo, los medios físicos para el mejoramiento y el mantenimiento de las cualidades de la tierra, se comparan con sus efectos en las cualidades de la tierra y en los resultados: 'análisis descriptivo insumos-resultados'. Esta información la necesitamos para el paso siguiente, al clasificar la aptitud de una cierta unidad de tierra (LU) para su combinación con un cierto tipo de uso de la tierra (LUT): 'clasificación de aptitud de la tierra prescriptiva'. Durante este paso segundo, se escoge para cada combinación de LUT y LU, la combinación I-LQ-Y, que situa la unidad de tierra LU en la clase de aptitud de tierra más alta posible. Esto es un proceso de optimación cuyos resultados dependen mucho del objetivo del uso de la tierra, que tiene que traducirse en criterios de aptitud de la tierra, detenidamente descritos para cada clase de aptitud.

Por fin llegamos a la conclusión general que el uso de modelos para la simulación de los procesos y actividades específicos del uso de la tierra ofrece perspectivas importantes para el análisis por sistemas. Tendrá que convertirse en el expediente imprescindible para los consejeros técnicos, a quienes se recurre en los países en desarrollo, en situaciones en las cuales las condiciones físicas y/o socio-económicas forman un impedimento serio para conciliar las cualidades de la tierra y los requerimientos de los tipos de uso de la tierra en el lugar en cuestión. También pa. los pronósticos a largo plazo y la reducción al mínimo de los riesgos para los agricultores de bajo ingreso que dependen mucho de las cualidades de la tierra dinámicos, como p.e. del agua disponible dichos modelos son de suma importancia. De momento, se podrá esperar el mayor beneficio de los modelos al describir y al simular procesos y mecanismos en el uso de la tierra, que se puede aislar facilmente: drenaje, labranza de la tierra, régimen de nitrógeno, disponibilidad del agua, rendimiento potencial. El uso de modelos matemáticos para simular todas las relaciones I-LQ-Y que fijan el comportamiento de LUS, de momento resulta demasiado complejo para poderlo aplicar en la práctica, durante una evaluación de tierras.

La evaluación de tierras tendrá que encontrar un compromiso entre las ideales científicas y las restricciones que surgen de la disponibilidad de datos, de la fidelidad de estos datos (p.e. de los parámetros hidráulicos del suelo) y de las posibilidades para el tratamiento de dichos datos. Sin embargo, la cartografía y otras investigaciones básicas de la tierra tendrán que aplicarse aún más que antes en la colección de datos que puedan caracterizar los factores del medio-ambiente y las cualidades de la tierra que son fundamentales para los procesos y mecanismos fisiológicos y agrícolas. Con esto se atribuye directamente a la posibilidad de simulación de uso de la tierra, con el fin de mejorar de esta manera, la posibilidad de pronosticar el comportamiento de sistemas de uso de la tierra específicos, pensando en primer lugar en los países en desarrollo.

"... one of the most inspiring aspects of soils is that they bear a vegetation... The whole complex of soils, crops and mankind should be the subject of inspiration to soil surveyors. Some will excell in theoretical aspects. Others in the more practical ones. It would be a tragic misunderstanding to think that these practical aspects are only secondary research subjects. On the contrary, they require a wide knowledge of soil science and a good understanding of the land-use problems involved. This is equally necessary when the soil scientist has succeeded in obtaining the close cooperation of specialists in other branches of agricultural science or engineering."

C.H.Edelman in "Applications of soil survey in land development in Europe" (ILRI, 1963).

1. Land evaluation : the purpose it serves

People have always been on the look out for land that suits their purposes: for building shelters, for providing food and fibre, for protection against wild animals, endemic diseases, war, floods, pollution, seismic or volcanic activity. Land that was unsuitable was left idle as long as possible: for example, clay soils too heavy to work were often ignored in favour of soils that were easier to cultivate.

Nowadays soil scientists are often asked to evaluate the agricultural suitability of land that has traditionally been left idle, or used only very extensively. This land may have been considered to be of no or low suitability by traditional farmers because of factors such as acidity, salinity, alkalinity or susceptibility to flooding or to erosion. But the increase in population and of their demands for agricultural produce and for space to meet their non-agricultural needs, such as urban development and road construction, are provoking rapid changes in traditional land use patterns. These changes include occupying new lands, or frontier development where land reserves still exist, as well as intensifying the utilization of already occupied lands, by applying new techniques and inputs to stretch its productivity or 'intensive margin'. Beside this rapidly increasing demand for land resources from many potential users there is also a growing awareness that the utilization of land resources must be carefully planned and controlled to meet the interests of present and future generations to conserve its productivity and the quality of the human environment.

All these changes in the demand for land and in the criteria for land utilization have stimulated the scientists responsible for the study of land resources to modify their methods of land resource evaluation. Land is a broader concept than soil:

- an area of the earth's surface; the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and the underlying geology, the hydrology, the plant and animal populations and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man (FAO, 1976, p.67).

Land evaluation has been defined by FAO (1976, p. 67), as:

- the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation.

Land evaluation has developed from soil survey interpretation and land classification. The terms 'land evaluation' and 'land classification' acknowledge that their object of study is land; the term 'soil survey interpretation' suggests that soil is the main object of study, restricting itself to the prediction of soil performance. Although soil is often the most variable aspect of the environment, soil survey interpretation also considers other environmental variables such as climate and hydrology (Bartelli *et al.*, Ed., 1966). An example is the USDA-SCS land capability classification, which is a product of soil survey interpretation: (Klingebiel and Montgomery, 1961). In a land evaluation for forestry or grazing purposes, however, the land attribute 'vegetation' is likely to receive more attention than the soil.

The term 'land evaluation' is preferable to 'land classification': the term 'classification' overemphasizes the importance of an arrangement of the land in classes. Land classification has also become synonymous with a number of specific systems, each of which has been created to solve a particular set of land use problems occurring in a specific physical and socio-economic environment.

An example is the United States Bureau of Reclamation (USBR) Land Classification System for Irrigated Land Use. (For descriptions of different land classification systems see Steele 1968; FAO, 1974a, 1975b; Vink, 1975) Although each system may serve its purpose perfectly well, and although, admittedly some successful adaptions of such systems to other environments have been realized, none of these systems has been universally accepted. Disappointment has resulted when land classification systems that originated in the developed countries have been transferred to the developing countries. In view of this, FAO has prepared a manual, entitled *Framework for Land Evaluation* (FAO 1976). This manual, intended to have world-wide application, is based on the concepts and procedures of land evaluation that have evolved during FAO-assisted development projects. (See Bennema, Beek, and Camargo, 1964; Mahler *et al.* 1970; the CSIRO/UNESCO Symposium on Land Evaluation, Stewart, Ed., 1968; the FAO/UNDP Latin American Seminar on Systematic Land and Water Resources Appraisal, Mexico, FAO 1971; Beek, 1972; and the FAO Expert Consultation on Land Evaluation for Rural Purposes, Wageningen 1972, Brinkman and Smyth, Eds, 1973.)

The *Framework for Land Evaluation* states that to serve its purpose, land evaluation should answer the following questions:

- How is the land currently managed, and what will happen if present practices remain unchanged?

- What improvements in management practices, within the present use, are possible?

- What other uses of land are physically possible and economically and socially relevant?

- Which of these uses offer possibilities of sustained production or other benefits?

- What adverse effects, physical,economic or social, are associated with each use?

- What recurrent inputs are necessary to bring about the desired production and minimize the adverse effects?

- What are the benefits of each form of use?

If the introduction of a new use involves significant change in the land itself, as for example in irrigation schemes, then the following additional questions should be answered:

- What changes in the condition of the land are feasible and necessary, and how can they be brought about?

- What non-recurrent inputs are necessary to implement these changes?

In summary it may be concluded that the purpose of land evaluation is to predict the inputs, outputs, and other favourable as well as adverse effects resulting from the action of the most pertinent types of land use that can be identified in connection with the land that is evaluated. To fulfil this purpose, the pertinent land use options should be identified at an early stage. This will be the main subject of the next chapter.

"When the cotton's picked
and the work is done
Boss man takes the money
And we get none."

Langston Hughes in
"Sharecroppers"

2. The land utilization type concept

2.1 Definition and comparison with other land use defining concepts

The definition of pertinent land use options has not always been satisfactory in land evaluation. In the past, land classification often resulted in the presentation of groupings of land/soil units according to their suitability for producing crops of economic significance (Jacks, 1946), either specific crops or a generalized equivalent: 'agriculture', 'horticulture', etc. A certain level of technology was usually assumed but seldom mentioned explicitly; other characteristics of the kind of land use in question received little or no mention at all. These land classification systems used to be primarily descriptive in terms of degrees of limitations of the soil for generalized land use purposes. Little attention was given to the real influence of these limitations on the performance of more specific types of land use. The groupings of land/soil units in capability or suitability classes were based on deviations from an 'ideal' soil/land tract, e.g. a soil that does not erode when intensively used, has no excess water problems, can be easily tilled, has adequate available water etc.

Aware of the need for precisely defined kinds of land use in systematic land evaluation Beek (1972) introduced the concept 'land utilization type' which was adopted in the *Framework for Land Evaluation* (FAO, 1976).

A land utilization type (LUT) is a specific way of using the land, actual or alternative, described for the purpose of land evaluation in the

following terms or key attributes (1) produce (e.g. kind of crop[1]), (2) labour, (3) capital, (4) management, (5) technology, (6) scale of operations. It is a broadly generalized equivalent of the management factor. The land utilization type is a technical organizational unit in a specific socio-economic and institutional setting, and related to other similarly selected land utilization types. Many similarities exist between the land utilization type and other land use defining concepts such as production systems, farming systems (Duckham and Masefield, 1970; Ruthenberg, 1976) and agricultural systems (Grigg, 1974; Dalton, 1975). The literature on these other land use concepts has been reviewed in Section 2.2.1.
For a better understanding of the land utilization type concept, some of the similarities and differences between the land utilization type and these other land use concepts will now be explained.

Land use systems, whether they have been named production, agricultural, farming, non-agricultural, recreational, urban, or any other kind of land use systems are integral systems and their purposes will include physical as well as social and economic considerations. Evaluating the performance of such systems needs to be based on an understanding of all underlying constituent processes and requires a synthesis of several disciplines such as agronomy, soil science, hydrology, economics. In view of the complexity of land use systems and the complicated interactions that occur between the various constituents of land use it will be difficult to take full account of the variation of each constituent in multidisciplinary farming systems research. Land evaluation contributes to the solution of this problem by carrying out a preliminary and partial but very systematic analysis of the variability of the physical land conditions and its influence on the performance of present and alternative land use systems, in such a way that its results can be easily absorbed by farming systems research and can ultimately serve an optimal land use planning.

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1 *The key attribute 'produce' should not be confused with 'productivity', a variable characteristic of the physical land conditions and of the overall land use system (see Section 3.1).*

To this end, accepting the risk of being criticized for over-simplification or superficiality, in this report the land use system has been arbitrarily subdivided into two constituent parts or subsystems: the physical land conditions and the use itself. The latter subsystem is key-named 'land utilization type'.

In this report an attempt will be made to treat the process of land evaluation systematically against the background of a land use system (LUS) which has been subdivided into a physical land constituent mostly described by land evaluators in terms of land (mapping) units (LU), and a land utilization type (LUT):

L U S	
L U	L U T

In this way it should become possible to predict the performance of present and alternative land use systems representing different land units/land utilization type combinations, taking into full account the differences and similarities between the land units identified during the land resources studies. In the *Framework for Land Evaluation* (FAO, 1976) the LUT is considered to be the subject of land evaluation whereas the land unit is the object of land evaluation.

Land evaluation takes into account previous farming system research results when identifying relevant land utilization types and analysing land suitability. The results of such land evaluation will, in turn, serve future farming systems research, regardless whether the land evaluation is carried out in parallel through some kind of integration with the farming systems studies or separately, possibly with some time interval between them.

The following simple example illustrates how different specializations may focus on the same subject using different techniques and criteria. A house will be looked at, classified and evaluated differently by: an architect; a person who intends to buy it for his home; a prospective investor; or by a municipal tax evaluator. All look at the same house from a different viewpoint with different classification criteria, because it serves a different purpose for each of them. In the same way, land is looked at by specialists from different disciplines involved in land use planning.

2.1.1 Who performs: the land or the use?

The terms soil performance and land performance are frequently used in soil survey and land evaluation reports. As already mentioned, the *Framework for Land Evaluation* (FAO, 1976) defines land evaluation as 'the process of assessment of land performance'. But there is remarkable confusion in the literature as regards who performs: the land, the crop, or the farmer. The solution to this paradox depends on the discipline of the specialist who is studying the problem: soil scientists will tend to attribute performance ability to a soil/land unit, while others, such as biologists and agronomists, are more likely to regard the soil as a medium affecting the crop's performance. A.A. Bishop suggested during a seminar at CIAT, Cali, Colombia (Bornemisza and Alvarado, Eds, 1974) that water management is more important than soil management, since all manipulations for optimizing the environment conditioning crop performance are ultimately concerned with the management of the liquid phase or, in other words, with water management. Conflicts also exist concerning the use of terms such as 'soil' potential or 'land' potential that do not connect the soil or land with a specific use.

In this report, the term 'performance' will be used in connection with expressions of inputs, outputs and other effects resulting from a specific LUT, LU combination. It has been decided that the performance of LUT and LU should not be assessed separately, but in a specific combination. This permits easy extrapolation to the performance of a land use system or farming system.

2.1.2 The need for land utilization types

There are several reasons for paying attention to land utilization types in land evaluation.

In the first place, the users of land evaluation data demand more precise information about land behaviour and land use performance. Land use planners want to include land evaluation results in their development plans, either very broadly or through precise optimizations, depending on the scale and purpose of their planning. This means that not only are qualitative expressions of land suitability needed;quantifiable assessments of inputs, outputs and other effects are also required. Such information can only be provided in conjunction with specific land utilization types.

A second reason for paying more attention to land utilization types is that land use planners increasingly face the problem of having to reconcile a multitude of social, technical and environmental criteria and constraints. In such cases, land evaluation can be of some help because alternative solutions for land use problems can be considered. These alternative solutions may comprise a variety of technical possibilities, which will often represent alternative types of land utilization. Depending on the situation, such alternative types may be closely related (e.g. alternative types of irrigated farming), or they may be as far apart as urban development, recreation and horticulture.

There is a third reason: in the past, different land classification systems were created for different types of land use - for example, the USBR Land Classification System for Irrigated Land Use and the USDA Land Capability System for Rainfed Conditions. One of the aims of today's land evaluation is to provide land use planners with information based on a methodology that uses the same concepts and procedures for any kind of land use so that comparisons and cross references are facilitated (FAO, 1976). Such a methodology is best served by a systematic approach to the kinds of land use considered, and of explicit mention of the assumptions that have led to their selection.

Only by precisely defining the land utilization types will it be possible to determine what are the specific requirements of land utilization that the land must meet, and how far the land that is being evaluated will meet these requirements. Often, land utilization types will have sufficient flexibility to adapt the land to their requirements through the application of inputs, e.g. of irrigation water to meet the water requirements, of fertilizers to meet the nutrient requirements, or of drainage measures to meet the aeration requirements in the rooting zone. Land evaluation should take into account the responsiveness of the land to the application of such inputs. A very common error with the application of the USDA Land Capability System in developing countries in Latin America has been the assumption, based on USDA practice, that all farmers will be able to use fertilizers. This assumption underestimates the limitation of soil fertility (often the most limiting soil factor in tropical countries) because the prevailing land use is quite different as it corrresponds to farmers who cannot afford or cannot take the risk of buying fertilizers, or live where fertilizer cannot be bought at competitive prices.

To sum up: land use performance and land suitability depend on intimate relationships between the land and the use. Therefore land evaluation should always take into account specific land utilization types, with specific land requirements. Noting the rapidly increasing number of land use systems and the enormous variety among them in their land requirements and in their abilities to manage, improve and conserve the land, the land utilization type itself should be an explicit subject of study and reporting in land evaluation.

2.2 Classification of agricultural land use

Do satisfactory procedures already exist, or should land evaluation develop suitable methods for identifying and describing land utilization types?

The literature on land use classification is very extensive, not only as regards local environments, but also for regional and worldwide conditions. But each source follows different rules and criteria according to the author's specialization and interest. Land use classifications have been presented in such varied fields as agronomy, agricultural statistics, geography and development planning. Now land evaluation is deliberately added to this list: during the FAO Expert Consultation of Land Evaluation in Wageningen (Brinkman and Smyth, Eds, 1973, p.9) it was recommended that:

> Agricultural and other rural land utilization types (including new types actively contemplated for the near future) be further examined and defined at different levels of generalization, by specialists and interdisciplinary working groups.

A broad classification of rural land utilization types was presented to the meeting (Beek, in FAO, 1974a) complemented by suggestions for further disaggregation and adjustment, emphasizing key attributes (Sect.2.3.2).

2.2.1 Literature review of land use classifications

The following review is necessarily selective and illustrative rather than exhaustive in discussing differences and similarities between land evaluation and other disciplines interested in land use characterization, in particular geography and agronomy. Because of the enormous variation in the ecological, socio-economic and cultural conditions, land use can be of many different types. Basically, each type represents a unique combination of the production factors land, labour, capital and management capacity in conjunction with a specific product, just like any other industry designed by man to satisfy his needs. According to Duckham and Masefield (1970):

> land utilization represents a judicious balance between the ecological potential, the operational potential, the input potential and level and the demand for its produce.

Land use classification has primarily been the concern of geographers responsible for studying the spatial variation of agriculture and for preparing present land use maps. Their emphasis varies according to specialization: physical geographers emphasize the importance of landforms, soils and climate on their land use classification. Human geographers stress the importance of population, location, markets, socio-economic development stage, farmers' motives and other related social and economic variables (FAO, 1965).

The geographer's task is primarily descriptive. But today he is increasingly concerned with analysing present land use systems on their development potential and with understanding the complex combination of factors involved in the transformation of traditional land uses (Kostrowicki, 1974; Kleinpenning, 1968; Gregor, 1970).

When formulating land use types, agronomists attempt to combine physical and socio-economic conditions 'to satisfy market demand with the maximum profit or domestic or social satisfaction' (Duckham and Masefield, 1970, p.3). Agronomists often refer to production systems, enterprises, farming systems (Lebeau, 1969; Duckham and Masefield, 1970; Ruthenberg, 1976) and agricultural systems (Grigg, 1974; Dalton, Ed., 1975; Westphal, 1975).

The agricultural typology of the International Geographical Union (IGU)

There is still no recognized international land use classification. The Commission on Agricultural Typology of the IGU has, however, prepared a provisional typology of world agriculture based on 22 diagnostic variables, each subdivided into a number of classes, mostly five, by distinguishing critical threshold values for each variable (Kostrowicki, 1974; see Table 2.1).

Table 2.1. Diagnostic variables for agricultural typology.

A. Social and Ownership

- land ownership
- land operation

B. Size of holdings

- number of actively employed people per holding
- total amount of arable land
- number of livestock
- gross agricultural output

C. Organizational and technical

- inputs of labour (per 100 ha and man days per ha per year)
- inputs of animal power per 100 ha
- inputs of mechanical power HP per 100 ha
- fertilizer NPK per ha
- irrigation (% of cultivated land irrigated)
- intensity of cropland use (harvested/total arable)
- perennial crops + semi-perennial (% of total cultivated)
- permanent grassland (% of total agricultural land)
- intensity of livestock breeding (units per 100 ha)

D. Production

- land productivity per ha
- labour productivity
- degree of commercialization (% of total produce sold commercially)
- level of commercialization (per ha)
- degree of specialization

E. Structural characteristics

- production orientation
- orientation of commercial production

Source: adapted from Kostrowicki, 1974

According to Kostrowicki (1974, p.2) the purpose of the IGU typology, like any classification is to

> organize our knowledge of the objects under study in such a way that their properties may be best remembered and their relationships more easily understood.

The final goal of the typology is the preparation of a world map of agriculture. To what extent can such a typology be used to explain relationships that exist between the type of agriculture and the land conditions? Kostrowicki (1974) recognizes the *ad hoc* value of the typology but says that

> the first studies of IGU on dynamics of spatial organization of agriculture, both for the past and for the future, including the progress and programmes of its future changes have been initiated.

However, the IGU typology of world agriculture is primarily a framework for the indication of differences and similarities in space, not in time. It is expected to influence the structuring of agricultural statistics and more detailed agricultural typologies. Kostrowicki (1974, pp.4-5) believes that a type of agriculture should be:

- a more or less established form of crop growing and/or livestock breeding for production purposes characterized by a definite set or association of its internal characteristics, developed and shaped by specific historical processes in given external and other conditions;
- a supreme concept in agricultural classification embracing all other concepts used in systematic or partial typologies (such as breeding, farming systems etc.);
- a hierarchical concept encompassing types of various orders, from types of world agriculture through several intermediate orders, down to the lowest order identified by grouping individual agricultural holdings;
- a dynamic notion changing in an evolutionary or revolutionary way along with a change of its basic characteristics.

It seems questionable if the four criteria can be met by the same typology.

The characteristics defining the agricultural type have been limited to its internal characteristics. The use of external variables, such as the physical environment, location, transportation, market conditions, prices, supply and demand of agricultural products, are, according to Kostrowicki, both dangerous and unfruitful because such factors should 'pre-suppose rather than prove their influence on the formation of agricultural types'. He nevertheless recognizes the importance of the external conditions in the formation of agricultural types and the need to study them in combination with existing agriculture for planning more rational types of agriculture and their spatial organization, which is also the ultimate goal of land evaluation.

The differences in purpose and therefore in the descriptions of agricultural types and land utilization types will now be clear:

The IGU typology selects and describes diagnostic land use characteristics for the purpose of preparing a present land use classification with a map that shows the spatial variation of present land use. The influence of the physical land conditions on the formation of the agricultural type and its performance is not considered. Therefore the definitions of the agricultural types are not functional in the sense that the relationships between land and land utilization can be easily deduced. The key attributes have not been selected and rated for explicit recognition of the abilities of the agricultural type to manage, conserve or improve the land, nor for an easy recognition of its land requirements. Land evaluation needs more functional descriptions to suit its purpose: the prediction of land use performance on the basis of a critical comparison of land requirements and land use abilities with the land conditions. Nevertheless the geographers' description of present land use provides a necessary reference for the process of identifying and describing alternative land utilization types for development.

Farming Systems

An important contribution to the global understanding of agricultural land use has been made by Duckham and Masefield (1970). Their concept of farming systems, like the IGU types of agriculture, departs from the individual holding as the unit of classification. Duckham and Masefield however represent the dynamic approach of the agronomist rather than the more static one of the geographer, and establish therefore a closer contact with land evaluation.

They attempt, especially for temperate countries, to

> systematize the analyses and syntheses of the many variables influencing the location, input intensity and food out-put of farming systems and to submit models thereof which are actually or potentially quantifiable.

The work represents a textbook on comparative agriculture that is usefully complemented by Ruthenberg (1976) who describes farming systems in the tropics.

Duckham and Masefield's main argument coincides with the approach to land evaluation followed in this report: the nature, location and intensity of land utilization are the product of the interactions between and within three groups of factors: ecological; operational; socio-economic. Duckham and Masefield (1970, p.xi) state that

> as yet, in many cases neither the relative importance of, nor the size of the interactions between individual factors or groups of factors can be quantified, but that nevertheless one can usually identify the critical factors or interactions in any area and offer tentative models of the major interactions; and that the simplest and most convincing way of illustrating the influence of single factors or of groups of factors, is to hold as many of the others as possible constant.

They decide on two major variables to classify the world's farming systems: the intensity of farming and the 'farming land use'.

Farming intensity means the actual sum of inputs, other than natural/ ecological factors, which has been (admittedly arbitrarily) subdivided into: very extensive; extensive; semi-intensive; and intensive.

'Farming land use' distinguishes between:

- tree crops
- tillage: ⩾ 75% of the ploughable land is in tillage crops or one-year fallow
- alternating: 25-75% of the ploughable land is in tillage which is alternated with grassland (mostly temporary leys) or with long-term fallow or forest regeneration
- grazing or grassland: (pastures and ruminant livestock): ⩾ 75% of the ploughable land is in temporary leys or permanent pastures. Land that cannot be ploughed is in cultivated grassland or grazeable shrub, scrub or natural grasses

Livestock occurs in all systems, but land use on grassland systems is usually confined to ruminants (cattle and sheep).

The classification also distinguishes between temperate and tropical systems.

Table 2.2 shows examples of 29 different combinations of the chosen criteria.

Table 2.2 Classification of Farming Systems

Duckham & Masefield farm. land use	Tree crops		Tillage with or without livestock		Alternating tillage with grass, bush or forest		Grassland or Grazing of land consistently in 'indigenous' or man-made pasture	
Farming intensity	Temperate	Tropical	Temperate	Tropical	Temperate	Tropical	Temperate	Tropical
Very Extensive Examples	Cork collection from Maquis in southern France	Collection from wild trees, e.g. shea butter	-	-	Shifting cultivation in Negev Desert, Israel	Shifting cultivation in Zambia	Reindeer herding in Lapland. Nomadic pastoralism in Afghanistan	Camel herding in Arabia and Somalia
Extensive Examples	Self-sown or planted blueberries in the north-east of the U.S.A.	Self-sown oil palms in West Africa	Cereal growing in Interior Plains of N.America, pampas of S.America, in unirrigated areas, e.g. Syria	Unirrigated cereals in central Sudan		Shifting cultivation in the more arid parts of Africa	Wool-growing in Australia. Hill sheep in the U.K. (Sheep in Iceland) Cattle ranching in the U.S.A.	Nomadic cattle-herding in East and West Africa. Llamas in South America
Semi-Intensive Examples	Cider apple orchards in the U.K. Some vineyards in France	Cocoa in West Africa. Coffee in Brazil	Dry cereal farming in Israel or Texas, USA	Continuous cropping in congested areas of Africa. Rice in S.E. Asia	Cotton or tobacco with livestock in south-east of the U.S.A. Wheat with leys and sheep in Australia	Shifting cultivation in much of tropical Africa	Upland sheep country in North Island, New Zealand	Cattle and buffaloes in mixed farming in India and Africa
Intensive Examples	Citrus in California or Israel	Rubber in S.E. Asia. Tea in India and Ceylon	Corn Belt of the U.S.A. Continuous barley growing in the U.K.	Rice and vegetable growing in south China. Sugar-cane plantations throughout tropics	Irrigated rice and grass beef farms in Australia. Much of the east and south of the U.K., the Netherlands, northern France, Denmark, southern Sweden	Experiment stations and scattered settlement schemes	Parts of the Netherlands, New Zealand and England	Dairying in Kenya and Rhodesia highlands
Typical Food Chains	A	A	A, B	A	A, B, C, D	A (C)	C (D)	C

Source: A.N. Duckham and G.B. Masefield, 1970, Farming Systems of the World, Chatto and Windus, London, p.106.

See text for explanation

In connection with these four kinds of 'farming land use', Duckham and Masefield present an interesting classification of typical food chains which is relevant to land evaluation as well. Each food chain represents a different input-output efficiency and has a different protein production capacity:

Foodchain	
A.	tillage crops/man
B.	tillage crops/livestock/man
C.	grassland/ruminants/man
D.	tillage crops and grassland/ruminants/man

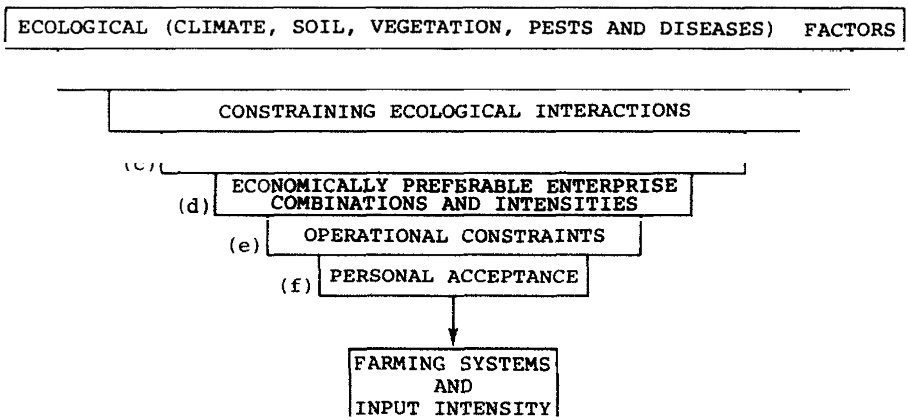
Duckham and Masefield list a number of criteria that should be met by a 'biologically efficient food producing system'. Some criteria are directly related to the production of the farming system ('nature proposes, man disposes'): maximize plant growth and minimize plant and animal wastages 'on farm'; optimize input ratios of energy in skill, man work, animal work, fossil fuel and scientific and industrial inputs. Other criteria are related to 'off-farm conditions': supply of sufficient calories to feed the population, adequate storage and distribution and processing facilities with minimum wastages 'off-farm'. All requirements have been further elaborated into a simple energy model.

Finally there are a number of non-energetic criteria to be met related to the continuity of the system; the system should be

- reliable between and within years, months and weeks
- persistent over decades (and centuries)
- be capable of reduction, expansion or adjustment to meet changes in demand

Duckham and Masefield also pay attention to the process of synthesis (Fig.2.1) and comparative analysis of farming systems, covering several aspects of the process which in the land evaluation procedure has been named 'matching' (see Section 5.4.2).

Fig.2.1 Theoretical selection of farming systems.
A stepwise procedure



Source: Duckham and Masefield, op.cit., p.96

Farming systems of the Tropics

These have been described by Ruthenberg (1971)[1], who takes into account farm management characteristics that reflect site-specific conditions and farmers' aims. Ruthenberg emphasizes the interactions between the technical and economic aspects of farming and makes the reservation that many more systems exist that have been described by him; nevertheless his classification is perhaps the most exhaustive of any in the existing literature. The diagnostic criteria on which his classification of farming systems is based have been listed in Table 2.3.

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Table 2.3. Diagnostic criteria for the classification of farming systems of the tropics
Source: adapted from Ruthenberg, 1971

I. Collecting Systems

II. Cultivation Systems

Criteria for the classification of cultivation systems are:

type of rotation

- fallow system
- ley system
- field system
- systems with perennial crops

intensity of rotation

- shifting cultivation
- semi-permanent cultivation/stationary cultivation with fallowing
- permanent farming

water supply

- irrigation farming
- rainfed farming

cropping pattern and animal activities: main crops and livestock activities

implements used for cultivation: beside several pre-technical methods (no implements, fire + zero tillage, cattle treading, planting/digging stick) the main division is: hoe farming or spade farming, farming with ploughs and animal traction, farming with ploughs and tractors

degree of commercialization

- subsistence farms
- partly commercialized farms
- semi-commercialized farms
- highly commercialized farms

III. Grazing Systems

Classification of grassland utilization has been subdivided into:

- total nomadism
- semi-nomadism
- transhumance
- partial nomadism
- stationary animal husbandry

The criteria from Table 2.3. were combined to give the major cultivation and grazing systems (collecting systems were not further elaborated by Ruthenberg) listed in Table 2.4.:

Table 2.4. Farming Systems of the Tropics

shifting cultivation

semi-permanent cultivation

- on fertile soils of humid areas
- perennial crops
- irrigation
- unregulated ley in the drier savannas
- unregulated ley in high altitude areas

regulated ley systems

- traditional smallholders
- settlement schemes
- large farms

permanent cultivation, rainfed

- tropical highlands
- African savannas
- monsoon Asia
- hot, humid tropics

permanent arable irrigation farming

- with individual water supply
- small schemes
- big schemes

perennial crops

- estates
- smallholdings
    - field crops
    - sugar cane
    - sisal
    - bananas
    - shrubs
    - coffee
    - tea
    - tree crops
    - cocoa
    - rubber
    - oil palm
    - coconut

grazing systems

- total nomadism
- semi-nomadism
- ranching

Source: adapted from Ruthenberg, 1971

Ruthenberg departs from the farm as a unit on which the various activities are functionally related to each other by the common employment of labour, land, capital and management. His farming systems cover the overall management characteristics of a farm. Duckham and Masefield mention the possibility that a farm may consist of one or more farming systems; their concept refers primarily to production systems or enterprises of which several can be combined. In Section 3.4 of this report it will be explained that land utilization types sometimes are complementary options for the same farm unit: 'multiple' or 'compound' land utilization types, to be distinguished from 'single' land utilization types. A land utilization type defined in great detail and combined with a specific land unit results in a land use system that is very similar to the farming system concept used by agronomists.

Agricultural 'systems'

In recent years, possible ways have been explored of studying whole agricultural systems, taking into account their multi-disciplinary nature and dynamic character, using a 'systems approach' (Dalton, Ed., 1975). The systems approach represents a methodology developed during the last ten years for describing and predicting the functioning of complex physical entities taking good notice of their internal structure and the cause-effect relations between the elements that are part of it. Also the relations between the system that is being examined and other systems in its environment are taken into account. Simulation and optimization with mathematical models are characteristic techniques of the systems approach, which was developed originally for solving complex multi-disciplinary problems to do with engineering (Forrester, 1968; Toebes, 1975). A summary of the state of the art in agricultural systems analysis is given by Van Dyne and Abramsky in Dalton, Ed., (1975) who discuss about one hundred such studies. The importance of studying whole agricultural systems is receiving international recognition, especially in connection with the development problems of low income farmers in developing countries. The dynamic aspects are treated more satisfactorily than in the more static and descriptive approaches already discussed, which have been adopted by geographers and agronomists.

However, the systems approach so far has produced mainly experimental results, useful for further refinement of methodology, and for the solution of site-specific problems, Van Dyne and Abramsky (in Dalton, Ed., 1975) conclude that 'there is an almost complete lack of treatment of spatial problems in simulation models; but spatial problems are handled in a number of linear programming models'. It seems that practical land evaluation should not expect agricultural systems research soon to provide a ready-made classification or methodology for identifying, describing and classifying the most relevant agricultural land use options for varying physical land conditions. Systems theory does provide valuable ideas for the systematic disaggregation of agricultural systems, significant for the solution of the questions that need to be answered during land evaluation. For practical purposes, land evaluation will, in the near future, be expected to make the definition of relevant land utilization types a part of its routine procedure. If agricultural systems analysis has been carried out already in the area where the land evaluation takes place, its results should provide an important reference. On the other hand, future agricultural systems analyses will benefit from land evaluations that have been carried out in the knowledge of the concepts and procedures of a systems approach, since both aim ultimately at the planning and realization of optimal land use. For that reason, the prospects for a systems approach to land evaluation have been discussed in Chapter 5 of this report.

The methods proposed in the next chapters can be implemented by the usual land evaluation teams, with consultant services of visiting agricultural economists and agronomists (Luning, 1973; de Jong, 1976, 1977).

2.3 The characteristics that the definition of a land utilization type should contain

The characterization of land utilization types may include a variety of factors according to the detail and purpose of the land evaluation study. This section deals only with the most fundamental characteristics that have a marked influence on the performance of the land use and which, for their significant role, have been named 'key attributes'. Leading questions, when selecting key attributes to form relevant land utilization types, are:

- are the key attributes relevant and sufficiently mutually exclusive in their influence on land use performance?
- can each key attribute be graded in a practical way, distinguishing groups/levels/threshold values that are relevant for the purpose of land evaluation?
- will the key attributes recognized permit identification of the land requirements and of the land management, improvement and conservation abilities of the land utilization type pertinent for systematic interpretation of the land resources data?

2.3.1 Who defines land utilization types? and when?

Often land evaluation serves a specific purpose, this having been broadly defined by the interested party who requested the study. Examples are land evaluation studies for the establishment of family farms in new areas, land evaluation for milk production or for the establishment of quick-growing tree species for pulp production. It will depend on who specifies the requirements of the land evaluation study, as to which key attributes are stressed, which key attributes receive only casual mention and which are not mentioned at all. The future land user is more interested in economic results, the government more in political results, than how these results are obtained. The key attribute 'produce' is named: pulp wood, or milk, but not which trees, which animals or which pasture grasses.

The definitions of land utilization types formulated by the commissioning authority of the land evaluation study may not be sufficiently comprehensive for all their land requirements and land management, improvement and conservation abilities to be identified.

Most existing land evaluation procedures somehow take into consideration broad types of land use, specific management practices, or even specific crops or species: land classification for irrigated agriculture, for arable crops, tree crops, pastures, horticulture, pine plantations, coffee, etc. However, in land evaluation reports it is rare to find systematic listings of all the assumptions made concerning the technical, economic and social aspects of the envisaged types of land use. The omission of land utilization assumptions may result in considerable confusion and difficulties with re-interpretation when assumptions change with time or become invalid.

So far, mention has only been made of land utilization types that are defined at the beginning of land evaluation to supply the user with an explicit list of the land use assumptions and to provide the land evaluator with the necessary references for identifying land requirements and land management, improvement and conservation abilities. Later it will be pointed out that these definitions in the course of land evaluation may be subjected to modifications and adjustments in the light of land evaluation results.

2.3.2 Key attributes of land utilization types

Produce is the most diversified and important key attribute. It determines to a great extent the essence of the other key attributes and of the ecological land requirements. Not only primary biological production is included (crops, pastures, forests), but also secondary produce (livestock, wildlife) as well as other produce resulting from land use, such as the leisure and satisfaction obtained from recreation, the satisfaction from being a private farmer, and the produce resulting from specific environmental protection schemes.

The description of produce should be as precise as possible, even in a small-scale land evaluation: natural pastures or cultivated pastures, annual crops or perennial crops, natural forest or cultivated forest for timber production or pulp. Further subdivisions can be made into single crops, groups of crops or rotations of crops which in the context of land evaluation have the same land requirements. When mixed cropping or rotational cropping represent an integrated production system, land evaluation should be undertaken for the produce combination, e.g. rotational strip cropping of cultivated pastures with annual fieldcrops (in the undulating Pampa of Argentina), and the double cropping of wheat and soya beans (in South Brazil).

Labour is a key attribute closely connected with the level of applied capital and technology and the labour requirements of the produce. Land may differ in its response to labour inputs. Manual labour mostly prefers the more easily worked 'light' textured sandy soils for cultivation, rather than the 'heavy' clay soils. Soils may also vary in their response to labour inputs for certain tillage operations such as weeding, due to differences in moisture and soil fertility. Land units may respond differently to seasonal fluctuations and this may result not only in different overall labour requirements but also in a different distribution of labour through the seasons and different labour peaks. Furthermore, land may differ in its response to labour inputs for land improvement and conservation (Strauss, 1969).

Besides labour intensity, other aspects such as labour productivity, labour absorption and labour substitution are important variables in land use planning. Therefore labour will usually be an important key attribute when constructing alternative land utilization types for land evaluation.

Capital. Technically it may be possible to condition virtually any site to satisfy a particular requirement of a land utilization type. However, the extent to which land conditioning occurs depends in practice on: inherent characteristics of the land conditions; the cost of modifying them in relation to the value of the desired product; and the availability of private and public capital.

Capital intensity determines the range of possibilities for applying technology for management, improvement and conservation of the land resources. A distinction is usually made between non-recurrent capital (e.g. for major land improvements, but also for important farm buildings and structures) and recurrent capital, required for the year to year manipulation of the land conditions (e.g. for fertilizers, fuel, maintenance of irrigation and drainage structures).

Depending on the local situation, several levels of capital intensity may be distinguished. Camargo *et al.* (1975) distinguish 3 levels for reconnaissance-scale land evaluation in Brazil; low, medium, and high, in relation to rainfed crop production. Mahler (1967) recognizes five levels in Iran for land utilization types which, on the capital intensive side, include irrigated farming, and on the capital extensive side, dry farming.

Management is a complex attribute usually expressed as 'management level' which needs constant consideration when defining land utilization types. It is closely related to capital intensity and technology, but also to the produce, the scale of operations and the labour intensity. It is perhaps the most difficult attribute to be handled as a variable. The cooperation of sociologists and farm economists will often be required. Management is responsible for the allocation of production factors and the timing of their applications, makes decisions within the range of possibilities provided by the other key attributes, and is thus to a great measure responsible for the realization of the potential productivity of the land indicated by the land suitability classification. Differences in management competence are found in all social strata and societies. In land evaluation it should be recognized that land may vary in its claim on management skill, because of different degrees of risk and uncertainty and different degrees of complexity in the solution of land use problems. This variation in land conditions may affect the management still required, for instance in the choice of crops, the timing of the operations and the kind and amount of inputs to be applied.

Apart from individual differences between farmers which are beyond the scope of land evaluation it will often be possible to distinguish more than one management level relevant to the area under study.

In less advanced stages of development, farmers' attitudes and preferences, (or religious beliefs), can greatly influence the actual results of potentially promising land and water development schemes and special attention must be given to these aspects.

Technology is a key attribute complementing the production factors capital and labour. For the purpose of land evaluation it is preferable to point out feasible land management and improvement practices, or at least a range of key techniques and corresponding inputs, because of their great influence on the land suitability classification.

Beek *et al.* (1964) in Brazil paid special attention to the source of farm power and accompanying sets of implements as a diagnostic key attribute for the definition of land utilization types, at the time named 'management systems'. Another aspect of technology that is closely related to the assessment of land suitability is the intensity of chemical fertilizer use. Kostrowicki (1974) in his typology of world agriculture distinguishes the following levels (in kg) of pure content NPK per hectare of cultivated land: 0-10-30-80-200 and more. Camargo *et al.* (1975) distinguish three levels in US dollar values of fertilizer applied in Brazil: no fertilizers; less than $ 50 US; and more than $ 50 US (1966 prices). The amount of fertilizer that can be bought for US $ 50 may vary substantially from one part of the country to another.

The source of farm power can be (Beek & Bennema, 1972):

- four-wheel and crawler tractors
- two-wheel and one-wheel power operated
- animal power
- hand power

A special aspect of technology in the definitions of land utilization types is the major improvements of the land conditions or *'key improvements'*, requiring specific practices for their use and maintenance and a certain response from the land to become feasible. Examples are: drainage (if needed specified according to type: gravity or pumping, surface or sub-surface), irrigation (e.g. by system: flood, border, furrow, sprinkler, drip), terracing. Such improvements modify the overall focus of land utilization. Land evaluation for development projects will often be concerned with comparing land utilization types with and without such major improvements, and therefore such improvements should be specifically mentioned in the definition of land utilization types.

The scale of operations poses limits to the size of the land area for which the land evaluation type is relevant. This may be the minimum size of a parcel of land needed to a certain kind of produce; it may also be the size of a farm if the produce of the land utilization type corresponds to the farm produce; occasionally the scale of operations will be related to a combination of farms when a very large scale of operations is required, e.g. multi-farm production of sugar cane, rubber, oil palm.

Sometimes the scale of operations has been established beforehand by the planning authorities, or depends entirely on the present scale of farm operations.

The scale of operations is closely related to most other key attributes. Its inclusion in the definition stresses the importance of economies of scale in relation to specific kinds of produce and the indivisibility of certain kinds of inputs, e.g. refrigerated milk tanks, sugar cane harvesting machines. These economies of scale can result in specific demands of the land utilization type regarding the size and shape of parcels, or the location of irrigation and drainage channels, which in turn may depend on the soil pattern or existing land consolidation.

Size and shape of parcels and the status of land consolidation and infrastructure are socio-economic attributes of the land. They may become objects of survey and evaluation together with the physical land attributes when they are considered limiting for development and their modification is contemplated; for instance in the Netherlands reallotment projects ('ruilverkaveling') and in rehabilitation projects of existing irrigation and drainage systems.

Economies of scale may interfere in land evaluation in several ways. For example, in developed countries land evaluation will often be interested in the minimum scale of operations required because of the minimum amount of capital and technological inputs applied. But in developing countries, land evaluation may need to account for a maximum scale of operations, set by the maximum physical labour capacity of the farmer and his family.

A list of 39 examples of land utilization types characterized by selected levels of the key attributes: produce, capital, technology and labour is presented in Table 2.5.

Produce has been classified into annual crops, semi-annual crops, perennial crops, natural grasslands, cultivated grasslands, forestry and mixed farming (crops with grassland).

Capital has been subdivided into non-recurrent inputs (three levels) and recurring inputs (three levels).

Technology has been symbolized by four levels of farmpower: hand, animal, two-wheel tractor and four-wheel tractor power.

Labour has been subdivided into three levels of intensity.

2.3.3 Key attributes and aggregational levels

Land utilization types can be defined at different levels of detail. The highest aggregational level corresponds to the smallest scale of land evaluation. The *Framework for Land Evaluation* uses the term 'major kinds

Table 2.5. The rating of key attributes for defining land utilization types. Source: Beek (1972), FAO 1974a

EXAMPLES OF LAND UTILIZATION TYPES	PRODUCE												CAPITAL						FARM POWER				EMPLOYMENT			FARM SIZE			TECHNICAL KNOW HOW LEVEL		
	CROPS							GRAZING		FORESTRY	MIXED		DEVELOPMENT INPUTS				RECURRING INPUTS														
	ANNUAL			SEMI-ANN		PERENNIAL		NAT.	CULT.		ANN.CROPS + CULT. GRAZING																				
	fruits & vegetables	industrial	field	fruits	industrial	fruits	industrial				industr. crops + c.g.	field crops + c.g.	low	medium	high	very high	normal	high	hand	animal	tract.2 wheel	tract.4 wheel + crawler	low	medium	high	small	medium	large	low	medium	high
NO IRRIGATION																															
DRY FARMING																															
small holding, hand labour			●										●				●		●					●		●			●		
animal labour			●										●				●			●				●		●	●		●		
modern			●										●	●			●	●				●	●					●		●	●
HORTICULTURE																															
annual fruits and vegetables, hand labour	●												●				●		●						●	●			●	●	
annual fruits and vegetables, modern	●													●	●	●	●	●			●				●	●	●				●
perennial fruits, hand labour						●							●				●		●					●		●	●		●	●	
perennial fruits, modern						●								●			●	●			●			●			●	●			●
MIXED FARMING																															
field crops, cultivated pasture, animal traction												●	●				●			●				●			●		●	●	
field crops, cultivated pasture, modern												●		●			●					●	●				●	●			●
AGRICULTURE																															
annual industrial crops, hand labour		●											●				●		●						●	●	●	●	●	●	
annual industr.crops, animal power		●											●	●			●			●				●		●	●	●	●	●	
annual industr.crops, modern, small plots		●												●			●	●			●				●	●					●
annual industr.crops, modern, large plots		●											●				●	●				●		●				●			●
annual field crops, hand labour			●										●				●		●						●	●	●		●		
annual field crops, animal power			●										●				●			●				●		●	●		●		
annual field crops, improved, animal power			●											●			●			●				●			●			●	
annual field crops, modern, large plots			●											●			●	●				●	●					●			●
annual field crops, improved terraced cultivation		●												●			●				●				●	●				●	
semi-annual industrial crops, hand labour					●									●			●		●						●		●	●	●		
semi-ann.industr.crops, improved, labour intensive					●									●			●				●				●		●	●		●	
semi-ann.industr.crops, modern, labour extensive					●									●			●	●				●	●					●			●
perennial industr.crops, labour intensive							●							●			●		●						●		●	●	●	●	
perennial industr.crops, labour extensive							●							●			●				●			●			●	●			●
GRAZING																															
natural grassland								●					●				●			●				●				●	●		
natural grassland, improved								●						●			●					●	●					●		●	
cultivated grassland (meat)									●					●			●					●	●				●	●		●	●
cultivated grassland (milk)									●					●			●					●		●			●	●			●
FORESTRY																															
commercial timber (traditional)										●			●				●			●				●				●	●	●	
commercial timber (intensive)										●				●			●					●	●					●		●	●
IRRIGATED																															
annual fruits and vegetables	●														●	●	●	●				●			●	●				●	●
annual industr.crops, labour extensive		●													●	●	●	●				●		●			●	●		●	●
annual industr.crops, labour intensive		●													●	●	●	●			●				●		●	●		●	
annual field crops, labour extensive			●												●	●	●	●				●	●				●	●			●
irrigated rice, fully mechanized			●													●	●	●				●		●			●				●
irrigated rice, labour intensive			●												●		●	●			●				●	●	●			●	●
SUPPLEMENTARY IRRIGATION																															
semi-annual crops				●											●	●	●	●				●	●				●				●
perennial crops							●								●	●	●	●				●	●				●				●
annual fruits and vegetables	●														●	●	●	●			●				●	●	●				●
PERMANENT DRAINAGE																															
"polder" modern, field crops			●													●	●	●				●	●				●				●
VINEYARDS																															
Mediterranean type, traditional, no irrig.						●							●				●		●		●			●		●	●		●	●	

of land use' for this level, e.g. agriculture, extensive grazing, dry farming, forestry. The key-words describing these major kinds of land use summarize a number of interrelated characteristics of land use that need not always be specifically mentioned, as long as they represent actual existing combinations of key attributes. But major kinds of land use that are statistical averages of types that in practice are highly disparate (for instance in level of technology and in level of capital input, as is the case when speaking of 'agriculture' in developing countries with dual economies), are not well suited as a base for land evaluation. In such cases subdivision into more realistic land utilization types of a lower order of aggregation is necessary. For example, in the *Perspective Study for Long Term Agricultural Development of Brazil* (SUPLAN, 1975) 'agriculture' has been subdivided into three categories according to the levels of technology: low-medium-high, not only for the statistical simulation of product supply and demand projections but also for the analysis of available and required land resources.

The detail of the definition of a land utilization type is expressed by the choice and detail of description of the key attributes. Differences and similarities between land utilization types should be recognizable not only for types belonging to the same aggregational level, but also for types of different levels of aggregation.

This can be achieved by describing the key attributes according to a pre-established hierarchical system of disaggregations for different levels of detail. For example the key attribute 'produce' could be broken down as follows:

- level 1 biological produce
- level 2 agricultural crops
- level 3 annual crops
- level 4 field crops
- level 5 maize
- level 6 hybrid maize, var. H-131

Precise disaggregations of key attributes will sometimes only be possible at the end of land evaluation, when the land conditions are well understood. That is why some land evaluation systems such as the USDA Land Capability System define the land use in very broad terms at the beginning and complement this information later with land use recommendations - the land capability units - which may include suggestions about the crops and varieties to be grown, the physical inputs to be applied, the timing of field operations etc.

The use of an hierarchical system in the definition of land utilization types would improve information flow between land use planning activities at different levels of generalization. For example, information about land suitability in connection with subsistence agriculture at the detailed level, can be incorporated more systematically in a regional or national development plan.

Whereas rules can be established for the disaggregation of key attributes, the choice of attributes and of their aggregational levels for a particular case will remain the responsibility of those who are in charge of the land evaluation. Sometimes additional key attributes will enter the definition as detail increases. A definition may combine key attributes of different aggregational levels. But key attributes that should be included in the definition are those that have a real influence on the results of the land evaluation: on the land suitability classification and on the land management, improvement and conservation recommendations.

Thus to sum up, the definition of a land utilization type should consist of a combination of carefully described key attributes, such as: produce, labour, capital, management, technology and scale of operations. Because of their close relationships, key attributes are identified simultaneously and described at the appropriate aggregational level, in accordance with the purpose and detail of land evaluation.

Key attributes are selected for their marked influence on the land requirements and therefore on the land suitability which depends on the land requirements and the land conditions. Descriptions of key attributes should be sufficiently informative for easy identification of the land requirements. The ecological requirements can normally be deduced directly from the key attribute 'biological produce'. Other land requirements regarding management, improvement and conservation may require the translation of key attributes in terms of abilities of the land utilization type to manage, improve and conserve the land. Therefore description of the key attributes should also take into account the need for an easy identification of these land use abilities.

2.4 The process of defining land utilization types

Definition of land utilization types is a synthetic process that begins with an analysis of fundamental references, and that should result in an analytical description in terms of key attributes as indicated in Section 2.3. Fundamental references are the broad fields of information that need to be selectively studied (see Section 2.4.1).

A convenient intermediate step for the synthesis of the diverse information contained in the fundamental references is the preparation of a structured checklist of major and minor determinants of land use. This checklist is an important part of the land evaluation report. It provides a background for periodic revision of land evaluation results.

Land use determinants are the first results of this analysis and serve as building stones for the construction of land utilization type definitions. In a physical land evaluation, i.e. in which only the physical land conditions are the object of comparison and evaluation, the land use determinants embody the fixed constraints and assumptions about land use in the classification of land suitability.

In Fig. 2.2 the process of synthesizing land utilization types has been summarized:

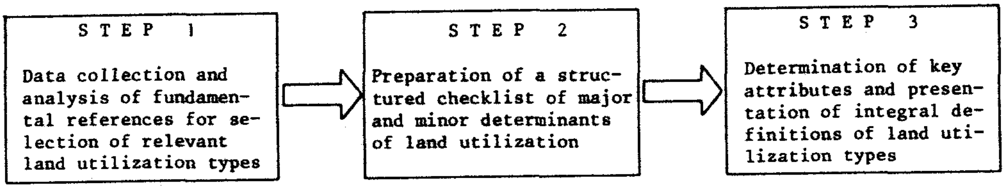
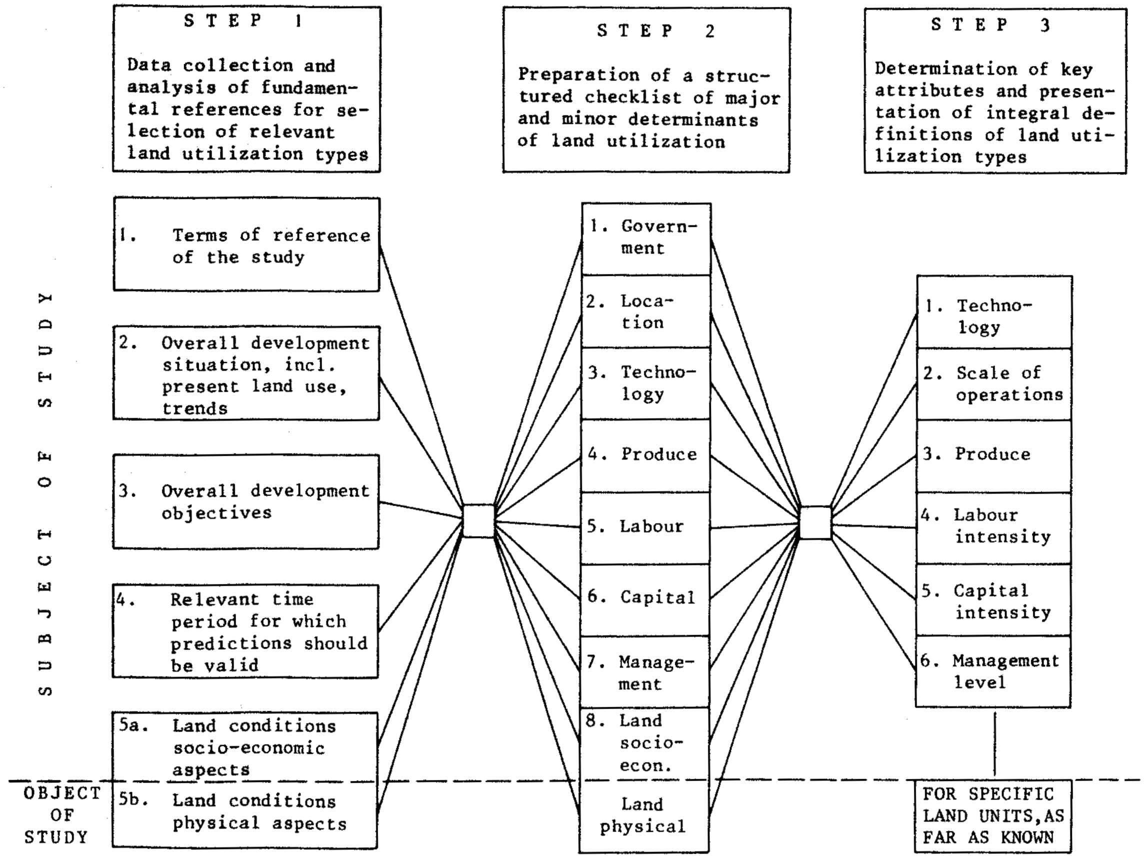


Fig. 2.2: The process of synthesizing land utilization types.

Basically this synthesis represents a preliminary form of socio-economic analysis. The scale and purpose of land evaluation and the availability of a specialist in this type of analysis determine what degree of quantification will be reached with the land utilization type definition. Land utilization types, which have been defined beforehand in the terms of reference of the land evaluation study ('pre-established' land utilization types) will often have been selected by a procedure similar to the one discussed here, but separate from the land evaluation study.

Fig. 2.3 presents a more detailed diagram of the process of synthesis of land utilization types. A horizontal broken line divides land in two parts: the lower corresponds with the physical land conditions and the upper part with the socio-economic land conditions. In the FAO Framework for Land Evaluation the terms 'object' and 'subject' of land evaluation have been applied to distinguish between the role of the physical land conditions and that of the land utilization type. The broken line in Fig. 2.3. should represent the divide between the object and subject of land evaluation. But this line does not represent an absolute limit. If some non-physical aspect or 'attribute' of land is known to be a variable of great significance, e.g. the degree of fragmentation of farm land or

Fig. 2.3: The process of synthesizing relevant alternative land utilization types.



the status of the infrastructure, this attribute may well be included as a variable object for evaluation. Neither should the possibility of an integrated multi-disciplinary approach to land evaluation, in which both the land utilization type and the land are object of study be excluded beforehand. After all, land use planning will most probably process the physical and socio-economic attributes of the land simultaneously in its search for optimal land use.

However, this report aims to contribute primarily to physical land evaluation, because the experience on which it is based stems from soil survey interpretation, which includes only physical land/soil conditions as object of study. References to land suitability classifications that include socio-economic land attributes have mainly been made to assure the general applicability of the concepts and procedures presented.

2.4.1 Fundamental references for identifying land utilization types

No relevant development alternatives should be overlooked when a first estimate of relevant land utilization types is made. Fundamental references for the selection and description of land utilization types are:

a) the terms of reference of the land evaluation study

b) overall development objectives and land suitability criteria

c) the overall development situation, in particular present land use, past trends and outlook for the future

d) the time period during which the land evaluation results should be relevant

e) the socio-economic attributes of the land

f) the physical attributes of the land.

a) Terms of reference of the land evaluation study

Sometimes the terms of reference include precise descriptions of land utilization types: land evaluation for 'pre-established land utilization types'. Otherwise, a careful analysis of the terms of reference needs to be made, complemented by criteria derived from the fundamental references b) to e) to assure the relevance of the utilization types considered.

b) Overall development objectives and land suitability criteria

The overall development objectives to which land evaluation is supposed to contribute are seldom made explicit in the terms of reference for land evaluation. It is mostly seen as the task of planners to assure that development proposals agree with both immediate and longer-term development objectives. This report views land evaluation as an integral part of systematic land use planning. Development objectives therefore are regarded as vital for the selection of land utilization types and also for the establishment of pertinent land suitability criteria. Examples of land suitability criteria are: optimal input/output relations; maximum labour absorption at a pre-established mimimum income level; sustained yields; minimal soil losses from erosion; minimum risk and uncertainty in meeting a certain income level (USBR, 1967; FAO/IBRD, 1970).

A long-term objective that is receiving a great deal of attention and which represents an important criterion for every land evaluation is the need for conservation of the quality of the environment. Land utilization types will differ in their abilities to conserve the land resource, an essential element of this. On the other hand, land resources differ in their capacity to respond to management without showing degradation, depending on the kind of land utilization.

If the relevance of certain land utilization types has to be tested in conjunction with specific environmental impact criteria, it should be realized that such an impact may be felt either on-site or off-site; in the latter case interfering with the functioning of other land utilization types. Another important consideration is the accumulated impact that may result from a full-scale implemention of land use changes on the area as a whole (see also Section 3.3.3).

If one of the suitability criteria should be that 'no erosion is allowed to take place' (viz. USDA Land Capability System), land utilization types that cannot meet this criterion will be irrelevant. In practice other land suitability criteria related, for instance, to acceptable input levels for soil conservation measures, may limit the range of relevant land utilization types even further.

Other major development objectives related to such diverse subjects as employment, income distribution and health may also affect the choice of land suitability criteria and land utilization types in different ways.

If the development objectives are included in the selection process of relevant land utilization types, the persons responsible for land evaluation will be given an opportunity of adding a certain measure of social awareness and responsibility to their otherwise essentially technical work.

c) Overall development situation and present land use

The overall development situation provides the socio-economic, demographic, legal, institutional and political setting of land evaluation and represents a valuable yardstick for the kind of development to which the land evaluation is expected to contribute. The development situation determines to a great extent the choice of the key attributes of the land utilization type and the method and procedure of land evaluation. Important aspects of the development situation are: population pressure, land/man ratios, land productivity and labour productivity, status of research, status of infrastructure, price policies, foreign trade, etc.

Present land use and past trends provide important evidence of the development situation in rural areas. Its outlook for the future can guide the selection of development alternatives. IBRD (1975) includes the following characteristics in the description of a development situation for the purpose of providing a context for land reform: land property concentration; social inequality; economic inequality; land productivity; labour productivity; level of technology; land tenure; labour intensity; capital intensity; production orientation (subsistence or market); supply of land resources (abundant or scarce); presence and degree of centralization of institutional structures; status of service structure.

The literature on development situations is mostly too general or too much related to a specific area or project to provide a systematic base for the typology of land utilization; more relevant literature for this purpose has already been mentioned in the field of agricultural geography and farm management (see Section 2.2; Sachs, 1974).

d) Time period during which the land evaluation results should be relevant

The time validity of selected land utilization types and of land evaluation in general should agree with the purpose of land evaluation. This may either be specified in the terms of reference or be left to the judgment of the land evaluator. Land utilization changes with time and therefore needs frequent modification. National and regional plans require reasonably stable interpretations with a validity of five or ten years, or longer in the case of long-term planning. Local land use plans usually require more precisely defined land utilization types including socio-economic assumptions whose life-span is likely to be shorter (Gonzalez *et al.*, 1977).

e) Socio-economic attributes of land

A distinction should be made between the socio-economic and the physical attributes of land. In most land evaluation studies only the physical land attributes are the focus of surveys and land evaluation.

Socio-economic attributes such as land tenure, location, land value, land consolidation status and land ownership are the object of other kinds of studies, e.g. cadastral studies, market studies and farm management studies. The socio-economic attributes of land represent an important reference for the selection of pertinent land utilization types, and assumptions regarding such factors will need to be formulated (Van den Noort, 1975; Feder and Manger Cats, 1971; Barraclough and Domike, 1966).

f) The physical attributes of land

In land evaluation as understood in this report the physical land conditions are the main object of study. Therefore their full consideration will only be possible at the end of the land resources surveys. But some generalized advance information about the physical land conditions for an early selection of relevant utilization types is usually available from existing information, or in the report of a project identification field party. This information should be carefully analysed and if necessary updated through another field visit. Physical land attributes may include soil, climate, hydrology, geology, topography, vegetation and fauna. Seldom will all physical land attributes be the object of study in land evaluation; for several of them only literature study may be contemplated, e.g. of hydrology and vegetation in soil survey for unirrigated agriculture.

Whatever fundamental references are consulted one should concentrate primarily on the collection of site-specific and research tested information. Sources and quality of the referred data should be mentioned and the standards of reliability for their adoption stated. In many situations, however, this information will probably need to be complemented by information tested elsewhere: knowledge transfer. An interesting qualitative classification of the nature of knowledge transfer has been suggested by Keller *et al.* (1973) who designed a strategy for optimizing research on agricultural systems involving water management. Their categories are:

- *explicit relationships* and formulas available for definite predictions

- *objective reasoning* based on some data points or a mix of data and theory: simple interpolations and empirical equations
- *subjective reasoning* based upon personal knowledge and experience is possible
- *unknown*: where it is not known if transfer of knowledge is possible
- *none*: where it is known that transfer of knowledge is not possible

Such qualifications can give important evidence of the confidence limits to be attributed to the land utilization types selected on the basis of analogy.

2.4.2 Preparation of a structured checklist of major and minor determinants of land utilization

Synthesis of land utilization types is likely to involve the consideration of many data and determinants of land use. To ensure that no important determinants are overlooked, and to summarize all this information, it will be convenient to prepare a checklist of the determinants of land utilization types. This list will need to be reproduced in the land evaluation report: for this purpose a structured list that distinguishes between major and minor determinants is preferable. Appendix 1 is an example of the items to be included in such a checklist, taking into account eight major determinants, each subdivided into a number of minor determinants. The major determinants selected are: Government, Location, Technology, Produce, Labour, Capital, Management, Land (socio-economic aspects). The physical aspects of land have not been included because these are explicitly discussed in other chapters of this report, although it is quite obvious that they are land use determinants, otherwise there would be no need for land evaluation.

The structured checklist of major and minor determinants embodies the justification for the land utilization types selected. It is a picture of ever-changing constraining land use factors and variables at the time when the land evaluation was executed. It should provide the necessary background information for a better understanding of the definitions of land utilization types.

When preparing a checklist of land use determinants it will be useful to distinguish between the present situation and the situation that would exist after the execution of improvements foreseen by the development plan or project to which the land evaluation contributes. Since information about the future development situation is likely to be very incomplete at the beginning of land evaluation when the checklist is compiled, revision and adjustment of this checklist and also of the land utilization types will be required at later stages of land evaluation, in the light of new information collected.

Land utilization determinants have a specific influence on the suitability of the land, an influence that may range from very slight to very strong. They need to be considered when the most promising land utilization types are being selected. For example: *land tenure* is a socio-economic attribute of land and appears in the checklist as a minor determinant of land utilization. It may affect the land suitability classification through its specific influence on the key attributes capital application, the kind of technology employed, the labour intensity, or the management level. If no changes in the land tenure are foreseen within the time perspective for which the land evaluation should be valid, the land tenure conditions act as an invariable determinant or fixed constraint on land use performance. If a future government chooses land reform as a major policy, this changes the major references on which the land evaluation is based; as a consequence, the determinants of the land utilization type change and the key attributes of the land utilization type will need to be revised accordingly. These changes provide the starting point for a revision of the land evaluation results reported originally. Sometimes there will be an opportunity to compare land suitability with and without the proposed land tenure changes, or to evaluate the effect on land suitability of other land tenure reform measures.

Location has been singled out as a separate major determinant of land utilization. Some doubts remain regarding the convenience distinguishing between the determinants 'location' and 'socio-economic attributes of land', which also touch upon some aspects of location. Location has been considered separately because of the importance of location zoning: the establishment of critical distances to input and output markets for different kinds of produce, especially in relation to bulky produce (wood, sisal, sugar cane). Land evaluation for very large areas, which include remote and sparsely populated parts (e.g. the Amazon Basin) could benefit from the consideration of location as a major land use determinant. In this case the relevance of a land utilization type would depend also on certain limits imposed by the location factor, e.g. the distance to the nearest major road or service centre.

For example: In a certain part of the Amazon Basin, exploratory land evaluation (scale: 1:1 000 000) includes the classification of land suitability for sugar cane, maize, rice and pastures. There is only one major road. The same land unit, a kaolinitic yellow latosol (LY 1) with semi-evergreen tropical forest (set) and a gently undulating topography (gu) can be found in different locations. For the selection of land utilization types the location factor is introduced as a major land use determinant by presenting the condition that: (A) for sugar cane, only land within 10 km from the road should be considered; (B) for maize and rice, only land within 20 km from the road should be considered, and (C) that for pasture, land up to 50 km from the road should be considered.

Presentation could look as follows:

land utilization type	land unit LY 1-set-gu					
	location A 10 km		location B 10-20 km		location C 20-50 km	
	class	extent	class	extent	class	extent
a) sugar cane	2	500 000 ha	not applicable		not applicable	
b) maize	3	500 000 ha	3	300 000 ha	not applicable	
c) rice	3	500 000 ha	3	300 000 ha	not applicable	
d) pasture	2	500 000 ha	2	300 000 ha	2	2 000 000 ha

In this example, suitability of land units will only be determined for those land utilization types that meet the criteria put forward by the land utilization determinants. This will require an overlay on the land resources map, indicating location zones with a distance of respectively 10 km, 20 km and 50 km from the main roads.

Location as a land attribute: Sometimes location becomes an object of study in land evaluation e.g. in Japan (Norinsho Norin-Suisan Gijutsu Kaigi, Ed., 1963). Location is no longer a land utilization determinant, presented as an overlay on the land resources map, which limits the choice and relevance of land utilization types. Location is now a land quality that determines the suitability class, according to the degree to which location meets the demands of the land utilization type.

Presentation of our previous example from the Amazon Basin would look as follows:

land utilization type	land units					
	LY 1-set-gu, phase A		LY 1-set-gu, phase B		LY 1-set-gu, phase C	
	class	extent	class	extent	class	extent
a) sugar cane	2	500 000 ha	3	300 000 ha	4	2 000 000 ha
b) maize	3	500 000 ha	3	300 000 ha	4	2 000 000 ha
c) rice	3	500 000 ha	3	300 000 ha	4	2 000 000 ha
d) pasture	2	500 000 ha	2	300 000 ha	2	2 000 000 ha

This example represents a land evaluation which beside physical attributes includes other attributes (location) as object of study. It is no longer a purely physical land evaluation.

This report is based mainly on experience in physical land suitability classifications in which location is not a variable. For instance, the exploratory physical land suitability classification of the Amazon region of Brazil did not include location as a variable. It was used however for the tracing of the Trans Amazon highway, to include the more fertile soils. Now that the road has been constructed, a subsequent more detailed land suitability classification for more precise purposes of land use planning could include location as a major variable, in accordance with the example presented.

Another important aspect of location is the distance from irrigation inlets to drainage outlets, and particularly the gradient, which determine the possibilities and costs involved for receiving irrigation water and evacuating drainage water and controlling the groundwater table. However, this is a physical land attribute that will be discussed further in Section 3.3 when the need to examine the relationship of a certain LUT and LU combination in conjunction with its broader environment are discussed.

Appendix 1: Checklist of major and minor determinants of land utilization types (an example)

1. *Government*: existing development plans and targets, such as projections for scales of operation, land reclamation and consolidation; labour absorption targets; farm income and labour income targets; production targets for specific produce; consumption targets of specific produce; import substitution of specific produce; export targets of specific produce; environmental control policies (soil conservation, flood control); financial policies: subsidies, taxation, foreign exchange; status of governmental services: research, extension, credit, supply of inputs, output processing, transport, storage, marketing; prices and price structure of inputs, outputs and trends observed.

2. *Location*: distance between residence and working place (production distance); distance to input and output markets: railheads, airports, ports, consumption centres etc. (market distance); critical distances to markets, both in terms of physical distance and costs; distance from service and research centres; distance from labour centres; distance from education and health facilities; competition from other areas; urban influences; natural interdependencies with other areas (water supply, drainage, land degradation); availability and local price deviations of inputs; means and conditions of transport; status of infrastructure (roads, harbours, rivers, airports, hazards such as susceptibility to obstructions such as snow, flooding, landslides, regulations regarding weight of vehicles, speed limits); relative environmental advantages compared to other areas (healthy overpopulated mountain areas, as compared to hot tropical jungle where life expectancy is shorter); intermediate handling cost related to distance from markets (packaging, storage, transport losses); cost of transportation (Found, 1971).

NOTE: When reporting on major and minor determinants, a sharp distinction should be made between the present situation and the options for development.

3. Technology: kind of techniques applied (cropping systems, fertilizer use, milking systems, tillage, harvesting, weeding, animal breeding and feeding, milk storage); specification of available animal/power traction and accompanying implements per hectare and per operational unit; supply of readily available and applicable techniques; scale of operations required for the application of specific techniques; status and outlook of research; status of educational facilities; predictive capacity of climatic and other environmental hazards; predictive capacity of market fluctuations and price relationships.

4. Produce: primary produce (crops, cropping systems, grasses, natural products); secondary produce (cattle, meat, milk, fish, charcoal, game, honey, but also the products of recreation, nature conservation etc.); observed yields and potential yields, yield trends; scale of operations required in relation to specific produce; availability of seeds, sperm, breeding animals, planting material; destination of specific kinds of produce (subsistence, industry, fuel, market, construction, food, fibre); age and overall condition of present perennial crops and animals; cattle reproduction rate and life expectancy; phytosanitary/animal sanitary conditions; overall cattle/land ratio; effective cattle density (cattle density and duration of pasturing on effectively grazed area of land); competition from substitute products; export prospects of specific produce; income elasticity of demand for particular produce and trends; prices and price structure of outputs and trends; marginal distances of specific produce to input and output markets (in effective length as well as cost).

5. Labour: availability (total; per operational unit, e.g. family, state farm, cooperative); kind (male, female, child; part-time, full-time; on-farm, off-farm); limits to scale of operations due to labour availability and distribution; educational level; specialization (e.g. experience with specific techniques or crops); labour density; trends: increase, outflow rate; seasonal distribution of available labour; seasonal labour absorption; labour income; labour productivity per time unit effectively worked; labour productivity per hectare; labour productivity per capital unit invested; capital invested per labour unit and trends; available land per labour unit and trends; occupied land per labour unit and trends; preferences of labour for specific kinds of work (e.g. resistance to animal traction); labour organizations strength and behaviour; value of leisure as compared to labour; mobility of labour; availability of off-farm labour opportunities; percentage of income derived from off-farm activities (rural and non-rural); effective animal labour inputs per hectare and seasonal distribution; effective mechanical labour inputs per hectare and seasonal distribution.

6. *Capital*: invested capital per operational unit and per hectare; on-farm available capital for investment, per hectare and per operational unit; off-farm capital available for investment; investment incentives and conditions; price of capital for investment and financing (interest rates, inflation, trends, alternative investment opportunities); kind of capital investment already present and its value: drainage, irrigation structures, buildings; kind and value of on-farm available animal traction, total and per hectare; kind and value of on-farm available power traction, total and per hectare; kind and value of off-farm available animal/power traction; cost of invested capital (interest, amortization, annuities); availability of non-recurring inputs; availability for maintenance and repair of machinery, equipment and installations, veterinary services; level of recurring inputs applied and trends, per operational unit and per hectare; prices of recurring inputs and trends; input levels (technical coefficients and value) of specific kinds of inputs (e.g. fertilizers, fuels, pesticides) applied per hectare; status of credit institutions and credit regulations; price structure and inputs.

7. *Management*: operational experience; commercial experience; technical experience: feeling for the use of equipment, machines; feeling for timing of operations related to climatic variation; feasibility and adoption rate of new techniques; specific social, religious and cultural values; degree of centralization of management decisions; freedom in timing of operations; ability to absorb inefficiencies in agricultural services; individual attitudes and outlook; levels of farmers' community

morale, solidarity and other group attitudes; efficiency in use of specific inputs; fertilizer use efficiency, irrigation efficiency; degree of specialization of individual and groups of farmers; effective/available labour ratio with seasonal fluctuations; orientation of specific produce components and overall production: subsistence, market, level and organization of product processing, storage, transport, marketing; levels of short-term and longer-term credit.

8. Land (socio-economic aspects): available land per inhabitant: man/land ratio; land ownership; land tenure; land prices and trends; transferability of land titles; security of land titles and status of cadastral services; status of physical infrastructure; form and size of land parcels; status of land consolidation; farm sizes, size of operational units, and trends observed; percentage share of different farm size groups; trends in land occupation and outlook; trends in land productivity and outlook; status of institutions and land legislation; land banks, water board, irrigation authority, soil conservation law and services; occurrence of endemic diseases (is sometimes a 'land assessment factor'); changes in land use and trends observed (diversification); present occupation of land; expected destination of land; trends and outlook in scale of operations; present land use intensity; status of unused land and amounts available.

3. Land requirements and land qualities

In agronomy the term '*requirement*' is commonly used when speaking of the specific land conditions required for the proper functioning of a certain crop (or agricultural implement). Examples of requirements include: water requirements, nutrient requirements and seedbed requirements of a certain crop; and the soil moisture and workability requirements needed by certain types of machinery during specific time periods of the year. These land requirements (LR) are the most fundamental aspects of the land utilization type for the purpose of land evaluation.

A very critical aspect of land evaluation is the availability of information about these land requirements, especially in developing countries. This information is often very difficult to obtain, and may be incomplete or vague. It is not unusual to find that handbooks on the cultivation of tropical crops give the ideal land conditions, which bear little comparison with the actual land conditions prevailing in the project area where the suitability needs to be evaluated. More useful are the descriptions of land requirements expressed in terms of relationships between different levels of specified land conditions and the corresponding levels of expected land use performance. Tables on pages 92-93 give an example, rating yield potential of a great number of crops as influenced by different degrees of soil salinity/alkalinity. Similar tables can be constructed to relate crop yield to variable degrees of soil moisture stress, or to levels of specified nutrients in the soil.

A land utilization type's land requirements determine to a great extent which land resource data need to be studied and in how much detail. In particular, the characteristics of the land that may not wholly meet these land requirements and which therefore represent potential constraints for the performance of the envisaged land use system should be examined. Advance information on the relevant land utilization types and their land requirements will increase the effectiveness and reduce the cost of field surveys and other studies on which land evaluation is based. This is not a new argument: survey and land evaluation criteria related to specific types of land utilization have also been used in the past - land classification for irrigation; soil survey and interpretation for rainfed agriculture; for intensive dairy production, etc.

This report emphasizes the importance of an analysis of the cause-effect relations between the land conditions and the land use performance that takes into account the specific land requirements of each land utilization type. To explain how such an analysis proceeds it will be necessary at this stage to explain briefly what is meant by *land conditions* and how they can be conveniently described for purposes of land evaluation (Section 3.1). After this digression we shall return to the main subject of this report: the land utilization types, and the systematic determination of their land requirements (Section 3.2). It must be said in advance that in this report the functional description of the land conditions and the land requirements of the land utilization types are considered to be the foundation of successful land evaluation.

3.1 Systematic disaggregation of land and the identification of land qualities

3.1.1 Land quality concept

The consideration of land from the viewpoint of individual disciplines results in an enormous amount of spatial and time-dependent data about each land attribute. Such inventorization often overlooks important relations and interactions between different land attributes. Moreover, users of the products of single-attribute surveys are frequently overwhelmed by data volume and technical jargon: significant details can easily be overlooked, particularly in land evaluation. Therefore ways must be found to synthesize the data into a more comprehensible form. Bennema (1976) sees one of land evaluation's tasks as the construction of simple models of the physical environment; but first and foremost these models should be product of synthesis of data rather than of elimination of data that are considered less relevant.

The concept of *'land quality'* has been developed for the exclusive purpose of synthesizing measurable single properties of the land into assessment factors that have a specific influence on the land use processes. The term 'quality' was used by Kellogg in 1953 to distinguish between two groups of properties that are important for evaluating the behaviour and potentialities of soils:

(a) the characteristics that can be observed directly in the field or examined from representative soil samples in the laboratory

(b) the qualities that 'may be interpretated from the observable characteristics and the results of field trials including the experience of cultivators, on areas of defined kinds of soils' (Kellogg in: *Desert Research*, Jerusalem, 1953, p.27.

Kellogg makes the important point that for the evaluation of optimal use and management of any specific kind of soil, combinations of the single observable and measurable characteristics must be interpreted. As examples of soil qualities for arid soil interpretation, he specifies soil drainage, salinity and alkalinity, tilth, fertility, erosion hazard, soil blowing, hazard of grading (the hazard of exposing undesirable strata from below the surface when grading and levelling the land for irrigation purposes).

The concept of land qualities was soon adopted in Brazil under the name of limitations (Lemos *et al.*, 1960, Bennema, Beek and Camargo, 1964), in The Netherlands (Vink (Ed.), 1963; De Smet, 1969; Van Dam, 1973; Gibbons and Haans, 1976) and in methods of land evaluation published by Beek and Bennema (1971) and FAO (1976). Bennema uses the term 'major land qualities' when referring to the main land characteristics that are important from the viewpoint of the user (the farmer, the hunter, the forester) and also from the 'viewpoint' of the plants, the animals and the agricultural equipment. There should be no conceptual difference between major land qualities and major ecological conditions. Bennema's definition of a major land quality is (Bennema,1972):

> A major land quality is a complex attribute of the land which acts largely as a separate factor on the performance of a certain use. The expression of each land quality is determined by a set of interacting single or compound land characteristics with different weights in different environments depending on the values of all characteristics in the set.

The following *broad types of land qualities* can be distinguished:

Ecological qualities of the land

These relate to the ecological land use processes and the ecological requirements of the land utilization types. Most agricultural land uses have at their core biological production processes of crops, or animals with specific ecological requirements for their physiological growth and development.

Examples are: availability of water and nutrients, temperature conditions, length of growing season, availability of drinking water for grazing cattle, photosynthetic capacity for producing carbohydrates and proteins.

A 'super' quality integrating several ecological land qualities is land productivity, normally expressed by the yield per hectare, obtained in combination with a specific land utilization type. Kellogg (1961) defines 'soil productivity' as:

> the potential for producing specified plants or sequences of plants under defined sets of management practices. It is measured in terms of outputs in relation to inputs for a specific kind of soil under physically defined systems of management.

Bennema (1976) observes that in cases when land evaluation is only asked to answer questions about the productivity levels of existing types of produce in the context of already established land utilization types, it will not be necessary to base the land evaluation on land qualities.

Productivity levels can be determined by direct observation and measurement in the field, and these can be extrapolated to other land units in the same area by methods of correlating yield data with local land characteristics.

But when considering new land utilization types in which yield cannot be measured, or when major land improvements are foreseen, land quality will be a useful concept for land evaluation. The rating of such land qualities can sometimes also be based on direct observation and measurement of natural phenomena, e.g. the natural vegetation, indicator plants, land use. Otherwise land qualities will need to be expressed in terms of values of their component characteristics, e.g.the expression of natural fertility in terms of values determined by soil tests, the expression of water availability in terms of water balances for specific land (mapping) units (Van de Weg *et al.*, 1975).

Management qualities of the land

Agricultural land use requires not only that crops and/or livestock grow, but also that the land is conditioned for optimal productivity: that the seedbed is prepared, the crop is sown, protected against hazards, pests, diseases, weeds, that it is harvested, transported and processed. Depending on the kind of land use these agricultural practices make specific demands on the manageability of the land. The possibilities for implementing the most essential agricultural management practices on the land should be rated by distinguishing relevant levels for each management quality of the land, according to the degree in which they meet the land requirements of the land utilization types.

Examples of management qualities of the land are: the possibilities of using certain kinds of traction, or implements, or transport during different seasons of the year.

Conservation qualities of the land

These represent the land's unique capacities to maintain the status of the above-mentioned land qualities (in particular its productive capacity) at pre-established levels. Another term could be the 'environmental control capacities' of the land. Conservation qualities are a measure of the land's resistance to land degradation processes that can be caused by certain kinds of land use.

For example, in the USDA *Soil Survey Manual* the soil conservation qualities are described in terms of erodibility or erosion hazards under defined sets of practices. The soils are grouped in five classes of erodibility: (1) none, (2) slight, (3) moderate, (4) high, (5) very high. The manual states that

> meaningful groupings of soils according to erosion hazard are accompanied by descriptions of the sets of soil management practices and cropping systems adapted to them (Soil Survey Staff, 1951, p.269).

Another example is the capacity of soils to recycle waste products. Knowledge of this ability is required when the land utilization type in question involves applying large amounts of toxic elements (e.g. heavy metals) in farm chemicals or other products that are incorporated in the soil. Some soils (latosols or oxisols) in the humid Tropics are known for their high biological activity combined with a voluminous water supply and good internal drainage conditions. Such soils probably have a higher capacity to recycle waste products from agriculture, towns and industries, than do the soils of colder and drier climates. On the other hand they depend more on their thin organic top layer for their nutrient cycle than do soils in other climates whose mineral parts contain more weatherable minerals and have a higher cation exchange capacity. Thus the hazards of losing topsoils through erosion should be a major concern in the humid Tropics.

Conservation qualities are firstly examined in relation to the land utilization types that are expected to act on the land unit in question. But sometimes the effects of adjacent or more distant land utilization types may be felt, e.g. the effects of deforestation or irrigation in the upper watershed on the groundwater table, the inundation hazards and the soil salinity of the bottom lands. In these situations the hazards posed to the environment by certain types of land utilization and the corresponding land qualities will need to be studied in a wider areal context (e.g. watersheds, irrigation districts) than these individual land units. The additional demands made on land evaluations in such situations have been further discussed in Section 3.3.2.

Improvement qualities of the land

Land units differ in behaviour when certain physical inputs are applied for their improvement: they have a different response to inputs or a different 'input application efficiency' (Bennema, 1976). Well-known are the differences in the application efficiency of irrigation on soils with a different texture and different infiltration rate or permeability. Another example is the variation in response to fertilizers and other chemical soil conditioners due to the presence of variable amounts of toxic elements or of unfavourable physical soil conditions, e.g. the differences in response to nitrogen fertilizers because of differences in aeration of the rooting zone caused by inadequate soil drainage (van Hoorn, 1958). Improvement qualities of the land are often inalterable, as they are mostly determined by soil characteristics that cannot be changed, such as texture, slope, soil depth or permeability.

The following list of major land qualities is taken from Beek and Bennema, 1972, pp. 22-24.

1. Major land qualities related to plant growth

   - availability of water
   - availability of nutrients
   - availability of oxygen for root growth
   - availability of foothold for roots
   - conditions for germination (seedbed)
   - salinization and/or alkalinization
   - soil toxicity or extreme acidity
   - pests and diseases related to the land, flooding hazard
   - temperature regime (including incidence of frosts)
   - radiation energy and photoperiod
   - wind and storm as affecting plant growth
   - hail and snow as affecting plant growth
   - air humidity as affecting plant growth
   - drying periods for ripening of crops and at harvest time

2. Major land qualities specifically related to animal growth

   - hardships due to climate
   - endemic pests and diseases
   - nutritive value of grazing land
   - toxicity of grazing land
   - resistance to degradation of vegetation
   - resistance to soil erosion under grazing conditions
   - availability of drinking water
   - accessibility of the terrain

3. Major land qualities related to natural products extraction

   - presence of valuable wood species
   - presence of medicinal plants and/or other vegetative extraction products
   - presence of fruits
   - presence of game for meat and/or hides
   - accessibility of the terrain

4. Major land qualities related to management practices in plant production, in animal production or in extractions

   - possibilities of mechanization
   - resistance to erosion
   - freedom in the layout of a farm plan or a development scheme, incl. the freedom to select the shape and the size of the fields
   - trafficability from farm to land
   - vegetation cover in terms of favourable and unfavourable effects for cropping

In Appendix 2 of Chapter 4 the definitions of several land qualities and their ratings are presented.

3.1.2 Measurement of land qualities

Land qualities can be described and rated independently to express the status of component regimes and properties of the environment during a particular time period. But the significance of these ratings and of the threshold values of component properties depends on how much is known about the specific land requirements of the use in question.

The kind of land use and the objectives of land use determine which land qualities are limiting and to what degree. The constraining effect of such land qualities will need to be assessed first for individual time-discrete land use processes and activities, and after that, by means of some kind of integration or critical path analysis, for the whole sequence of time-overlapping land use processes (Visser, 1977).

Land qualities can provide a link between land resources inventories and land use planning by identifying the properties that merit observation, measurement and classification, and by suggesting the detail, in terms of number and density of observations, that is required. We measure only the essential qualities of the land so they can be used as independent determinants of the land quality-dependent effects or 'outputs' resulting from a specific combination of land (mapping) unit and land utilization type (yields, erosion losses, etc.).

Vink (1975), in a book that gives a thorough treatment of land use in advancing countries and contains many references to soil survey and land evaluation, concludes that 'the study of land qualities is an essential factor in the development of more complicated systems of land evaluation'. However a more fundamental approach to land evaluation should not necessarily be more complicated. Simplification will be possible if we succeed in mobilizing the soil surveyor's capacity for observing natural phenomena, by trying to measure (at least on an ordinal scale) some of the land qualities directly in the field. The soil drainage classes of the USDA *Soil Survey Manual* are an example. Such measurements require correlation, calibration and refinement with additional ratio scale measurements in the field and in the laboratory. Refinement of the techniques of interpretation of soil resources inventory data in general will generate critical questions about the accuracy of the data base (for example, concerning the variation in the measured soil properties and the degree of heterogeneity of soil/land (mapping) units). These (mapping) units for planning purposes will be handled as homogeneous land areas with a homogeneous performance. Soil resources inventory reports need to be very explicit on this subject of variability vis à vis accuracy.

There is still much to be achieved in the quantitative measurement of land qualities. They are usually ranked on an ordinal scale: high-medium-low-very low, using threshold values of component properties to distinguish different levels.

In The Netherlands, where most of the soil properties that contribute to land quality are measured on a ratio scale, the land qualities themselves are mostly rated on an ordinal scale (see Table 3.1).

When measuring and rating land qualities it will be useful to distinguish those threshold values of component properties that are pertinent for the use in question, e.g. in soil salinity, soil fertility, erosion hazard. For example the limit of -300 cm water moisture suction in the top 5 cm of the soil during one week is a threshold value for the land quality 'workability' in springtime in The Netherlands (Wind, 1976). The threshold value depends on the type of land utilization. When recommending sugar beet production, the moisture suction value of the top 5 cm of the seedbed must be known; but for potatoes, the moisture condition of the top 7 cm of soil is required. For grain production, the information is required for only a few centimetres depth, as these seeds require a shallow seedbed.

Table 3.1 Site-conditions, adopted in The Netherlands

Site-conditions[1]	Regarded as relevant for				Levels or gradations		Desired level determined	Refers to		Nature of condition	
	arable farming & hortic.	pasture production	forestry	recreation	recognized	quantitatively expressed		basic processes	management system	chemical	physical
drainage status	×	×	×	×	×		×	×			×
moisture supply	×	×	×	×	×		×	×			×
workability	×				×		×		×		×
structural stability	×				×		×		×		×
HCl-reaction/ lime content	×				×	×	×	×		×	×
bearing capacity		×			×	×	×		×		×
spring earliness	×	×			×		×		×		×
nutrient status			×		×		×	×		×	

[1] In The Netherlands the Dutch term *hoedanigheden* has been translated as *site conditions*, *assessment factors*, and *soil qualities*.

Source: Gibbons and Haans, 1976

The definitions of land qualities for reconnaissance type land evaluation in Brazil also reflect the influence of land use in the way the land qualities are rated. Thus, for example:

> Grades of natural fertility
>
> (simplified definitions, see also Section 4.3.4 and Appendix 2)
>
> very high/high
>
> soils with high level of available nutrients ...
>
> When the other four factors (land qualities) are also favourable, nutrient reserves allow good yields for many years, also for the more demanding crops ...
>
> medium
>
> soils in which the reserve of one or more available plant nutrients is small ...
>
> When the other factors (land qualities) are favourable, nutrient conditions only permit good yields of annual crops during the first few years: after that yields rapidly decrease, when agricultural use of the land continues ...
>
> low
>
> soils in which one or more of the available nutrients appear only in small quantities.
>
> When the other factors are favourable, nutrient conditions only permit a reasonably good yield for adapted crops ...
>
> very low
>
> soils with a very restricted nutrient content, leaving the soils practically without any possibility of agricultural pasture or reforestation use ...

Some land qualities have received more attention than others and attempts have been made to describe and rate them quantitatively because of their dominating role in the planning of optimal use and management.

A good example is the Universal Soil Loss Equation of Wischmeier and his efforts to relate soil properties to its inherent erodibility (Wischmeier, 1959, 1976; Wischmeier and Smith, 1960, 1962, 1965; Rauschkolb, 1971; FAO, 1977c; Moldenhauer, Wischmeier and Parker, 1967; Wischmeier and Mannering 1969; Hudson, 1971; Constantinesco, 1976).

The Universal Soil Loss equation reads:

$$A = R \times K \times L \times S \times C \times P$$

A = soil loss
R = rainfall erosivity
K = soil erodibility
L = length of slope
S = steepness of slope
C = crop management
P = conservation practice

This equation relates the expected soil erosion loss A with the major land quality resistance to erosion (expressed by the 'component land qualities' R,K,L and S) and with the land utilization type (expressed by the attributes C and P). We may consider the soil erodibility factor K a component or 'minor' land quality as compared with the major land quality 'resistance to erosion'. In a five-year field, laboratory and statistical study including 55 selected Corn Belt soils, Wischmeier and Mannering (1969) derived an empirical equation for calculating the erodibility factor K:

$$K = 0.013\ (18.82 + .62X_1 + .043X_2 - .07X_3 + .0082X_4 - .10X_5 - .214X_6 + 1.73X_7 - .0062X_8 - .26X_9 - 2.42X_{10} + .30X_{11} - .024X_{12} - 21.5X_{13} - .18X_{14} + 1.0X_{15} + 5.4X_{16} + 4.4X_{17} + .65X_{18} - .39X_{19} + .043X_{20} - 2.82X_{21} + 3.3X_{22} + 3.29X_{23} - 1.38X_{24})$$

The X terms represent the following soil properties and combinations of them:

X_1	% silt x 1/% organic matter
X_2	% silt x reaction
X_3	% silt x structure strength
X_4	% silt x % sand
X_5	% sand x % organic matter
X_6	% sand x aggregation index
X_7	Clay ratio
X_8	Clay ratio x % silt
X_9	Clay ratio x % organic matter
X_{10}	Clay ratio x 1/% organic matter
X_{11}	Clay ratio x aggregation index
X_{12}	Clay ratio x 1/aggregation index
X_{13}	Aggregation index
X_{14}	Antecedent soil moisture
X_{15}	Increase in acidity below plow zone
X_{16}	Structure
X_{17}	Structure strength
X_{18}	Structure change below plow layer
X_{19}	Thickness of "granular" material
X_{20}	Depth from "friable" to "firm"
X_{21}	Loess = 1; other = 0
X_{22}	Over calcareous base = 1; other = 0
X_{23}	% organic matter x aggregation index
X_{24}	Reaction x structure

The K values found with the equation were tested against benchmark soils from the older erosion-research stations for which the K factor is known. The results confirmed that this empirically found equation is generally applicable over a broad range of medium-textured soils.

Rating of land qualities quantitatively is also very important in solving problems related to water deficiency in the soil. Dimantha's

(1977) study is interesting: he developed a numerical soil moisture simulation model for land evaluation and land use planning, and attempted to synthesize the dynamic properties of a soil in Sri Lanka to characterize the land quality 'available water'.

A quantitative approach to the measurement of the land quality 'available oxygen' will be of major concern in situations where land use is confronted by serious land drainage problems. In The Netherlands, for instance, an analog simulation model of the non-steady unsaturated flow of moisture has been developed (Wind, 1976) to predict the moisture suction of the topsoil during springtime, an essential piece of data for the timing of field operations. The model also permits simulation of different tile-drain spacings and depths for optimizing the drainage conditions. Such a model can be most valuable for land use planning, reducing the risk and uncertainty related to the timing of ploughing, seedbed preparation, sowing, etc. It could be applied to land use problems in developing countries if the necessary data were made available: the rainfall data for a long enough period, the evaporation, the runoff, the infiltration rate, and the moisture characteristics of the soil.

The model is based on the following relationship between soil moisture tension and capillary conductivity: $k = k_o e^{\alpha\Psi}$ (Rijtema, 1969).

k = capillary conductivity ($cm.day^{-1}$)

k_o = capillary conductivity at zero suction

Ψ = moisture suction topsoil (cm)

α = soil parameter

In situations where land use performance depends entirely on the natural soil conditions (as is often the case in forestry, extensive grazing and traditional agriculture) precise measurement of the land quality 'soil fertility' will be of paramount importance. Because of the interactions between the many factors influencing plant growth, multiple correlations will often be more revealing than single correlations, e.g. with soil phosphorus, with pH or with organic matter. This is illustrated by van Goor's work on growth-site relations in Sao Paulo, Brazil, with *Pinus elliottii* and *Araucaria angustifolia*. Since these tree species are grown without fertilization, the analysis of site factor-growth relations directly influences the land suitability classification (van Goor, 1965/1966; Bastide and van Goor, 1970, Bennema and van Goor, in FAO, 1975a). Sixty-five percent of the growth differences in *Pinus elliottii* and 50 percent in *Araucaria* could be explained by differences between land units, or more specifically between the soil types, the natural vegetation types corresponding with these soil types and the land use history. Consequently land suitability classification on the basis of the existing (reconnaissance) soil map became relatively easy. By adding the land quality 'soil fertility' to the land units and the land use history, 70-75 percent of the growth differences could be explained. Mathematical methods of principal component analysis and non-linear curve fitting proved helpful in explaining the influence of separate components and their constituent parts composing the land quality 'soil fertility'. The principal components that could be identified were: the adsorption complex comprising pH, amount of exchangeable bases and aluminium saturation; the organic matter component comprising carbon, nitrogen and phosphate; the third component consisted only of phosphate. The latter information on the influence of land quality components is significant for land utilization types that include the fertilization of forest plantations in their management practices.

Principal component analysis has also been successfully applied by Kyumi and Kawaguchi (1972) for the capability classification of soils for paddy rice. Eleven selected character data of 417 paddy soils from South and South-east Asia were related to outputs, which resulted in a so-called 'soil chemical potentiality' classification.

On land improvement qualities and input application efficiency

Land (mapping) units may differ in certain characteristics influencing the amount of input needed, although the unimproved levels of the land quality that needs improvement may be very similar, while the other land qualities also do not vary significantly. Examples of such characteristics are: the presence of toxic amounts of certain chemical soil components which cause the fixation of fertilizers; differences in soil texture, in infiltration rate or in permeability which affect the amount of irrigation water that needs to be applied or the rate of nitrogen mineralization.

Bennema (1976) uses the term *'land improvement qualities'* for such factors that independently influence the efficiency of input application. Their values can only be determined when both the land and the use, including the kind of input, the method and time of input application and the foreseeable input levels are known.

The values of land improvement qualities (IQ) often depend on the status of uncontrollable or only partly controllable land properties such as soil texture, slope and soil depth. For instance in irrigation much attention is given to the levelling of the land to maximize the field application efficiency of the irrigation water. Nevertheless substantial differences may be observed between fields having different soil texture. An example is Figure 3.1 (from Bos & Nugteren, 1974), in which the field application efficiency (e_a) of irrigation water has been expressed graphically in relation to the soil texture. Different relations are found for different input application methods: basin (continuous), basin (intermittent), flow, and sprinkler irrigation. Differences in e_a of ten percent between light and heavy textured soils are common. There is a very great difference in efficiency of continuous basin irrigation between heavy soils and light textured soils.

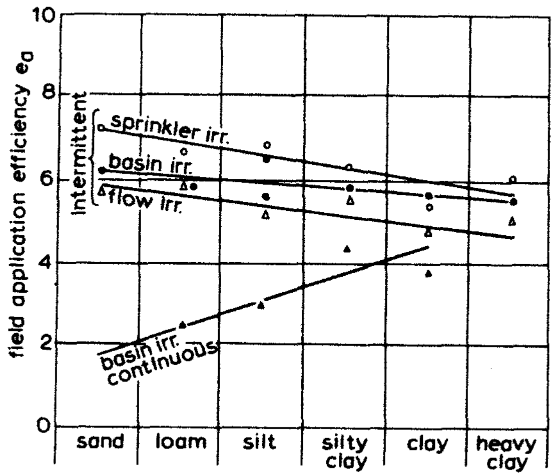


Fig.3.1: Field application efficiency and method of irrigation with reference to soil type. Source: Bos and Nugteren, 1974.

The identification of land improvement qualities (IQ) and the grouping of land (mapping) units into populations of defined levels of IQ is a major responsibility of those who study and interpret land resources. For example:

> the regression line expressing input-output relations in Fig. 3.2 for selected land (mapping) units that have a low soil test value of available phosphorus (land quality value) could (at least conceptually) be further refined. To do this the land (mapping) units would have to be partitioned into categories, each with a different input efficiency (IQ) attributable to a measurable characteristic, e.g. the phosphorus fixation level.

The most useful studies of land improvement qualities (IQ) will be those that aim to understand and describe the process underlying the conversion of inputs into outputs, e.g. the study by simulation of nitrogen behaviour in soils (Beek and Frissel, 1973; van Keulen, 1977); To explain input-output transformation processes it will be necessary to identify the measurable characteristics of the land (mapping) unit that determine this land improvement quality IQ: I shall refer to such characteristics as 'land improvement quality determinants' (IQD) of the land.[1] The soil texture in Fig. 3.1 is an example of a land improvement quality determinant of irrigation water. Within the textural classes referred to: sand; loam; silt; silty clay; clay; heavy clay; great differences may be observed in, for example, infiltration rate, moisture retention curves (pF) and permeability. However, data on soil texture are more often available from soil survey and other research reports than are other, more specific determinants of irrigation water application efficiency.

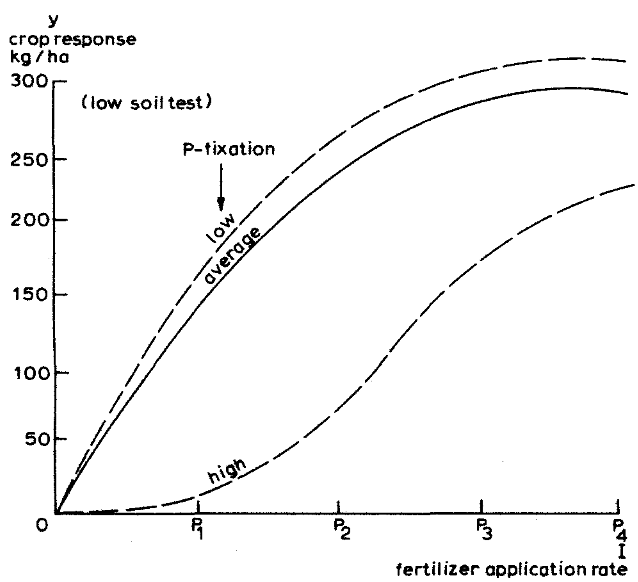


Fig. 3.2: Hypothetical partitioning of low phosphorus soil test population in two sub-populations with different P-application efficiencies (IQ) based on differences in aluminium saturation.

The infiltration rate is an important land improvement quality also for other land improvements such as desalinization and erosion control. The infiltration rate itself can be measured directly, but its values again depend on smaller elements of the system that is analysed, but which will not always be necessary to question during land evaluation. Correlation of values of IQ with values of their determinants (IQDs)

1 *Similarly the characteristics that determine the values of the parameter LR (land requirement) of a land utilization type could be named 'land requirement determinants' (LRD).*

will mostly be empirical rather than functional. The deeper systems analysis digs into the relation structure of the land use system, by subdividing it into smaller and smaller elements and sub-elements, each level being characterized by a more detailed structure of relations between the composing elements, the more likely will it be that the explanations for the observed phenomena become empirical.

Empirical explanations have been quite useful in the past for assessing the responsiveness of land units to specific inputs and for comparing different land units on their responsiveness to such inputs. For instance, at this moment there is still some speculation about the role of exchangeable aluminium in the soil chemical processes that determine the uptake of phosphorus by plants. But enough is known from empirically established correlations to predict from measured amounts of aluminium how an aluminium problem should be handled in practice: the amounts of lime required to neutralize the aluminium and to guarantee a satisfactory response to phosphorus fertilizers.

The transfer of values of land improvement qualities from places where these values have been (empirically) determined to other areas requires a careful comparison of similarities and differences between the areas concerned, in particular between their determinants (IQD). An example is the transfer of formulas for drain spacings that include IQ values empirically determined in the Netherlands to solve drainage problems in countries with different soil and climatic conditions, e.g. Portugal. Or the transfer of experience with drip irrigation in a low rainfall area in Israel to a no rainfall area with soil salinization problems in Northern Africa.

An interesting reference to land improvement quality determinants (IQD) in soil fertility evaluation is Buol *et al.* (1975), who have presented a technical classification system for grouping soils with similar fertilizer limitations. They defined quantitative values for selected soil parameters (see Table 3.2) that are expected to act as critical levels. Some of these critical levels have been found to correspond with different fertilizer response patterns, especially when they are combined with information about critical levels of land qualities (plant nutrients) determined by analysing land quality-output relations. Therefore some of these selected soil parameters should be helpful in the search for land improvement quality determinants (IQD) connected with the improvement of soil fertility.

Buol *et al.* use the term 'conditioner modifiers' for such soil parameters, suggesting that the critical values modify the effect to be expected from a certain conditioner, or in other words from a certain type of fertilizer or other input affecting soil fertility. However, the term 'modifier' implies that an 'ideal' soil exists which does not have this problem of a modified response from inputs. The 'ideal' soil concept and the description of land capability in terms of degrees of limitation or 'deviation' from this 'ideal' soil, is a well known approach to land capability classification in the USA (USDA Land Capability System). But in this report, and also in the *Framework for Land Evaluation* (FAO, 1976), each land unit is described in its own right, without comparison with 'better' soils. The land qualities describe the land unit's status in terms of measurable characteristics: in addition, the discussion on land improvement qualities in this report should eventually lead to the identification and measurement of land improvement quality determinants. The 'ideal' soil concept must be rejected, because the land utilization type determines what type of land is 'ideal': 'ideal' soils for cocoa, maize, rice or coconuts should have quite different characteristics. By analogy, the land improvement quality determinants should be related primilarly to the type of inputs they are supposed to influence and the specific method of input application e.g. broadcasting versus placement of fertilizers (de Wit, 1953).

To sum up: describing the land improvement qualities (IQ) of a land unit in terms of measurable values of land improvement quality determinants, IQD, could become a useful tool for land evaluation, for local application as well as for the transfer of accumulated knowledge to other areas. Such data should complement the information about

Table 3.2. Fertility-Capability Soil Classification System: 1974 Version

TYPE:

Texture is average of plowed layer or 20 cm (8 in.) depth, whichever is shallower

S = Sandy topsoils: loamy sands and sands (USDA)
L = Loamy topsoils: < 35% clay but not loamy sand or sand
C = Clayey topsoils: > 35% clay
O = Organic soil: > 30% O.M. to a depth of 50 cm or more

SUBSTRATA TYPE:

Used if textural change or hard root restricting layer is encountered within 50 cm (20 in.)

S = Sandy subsoil: texture as in type
L = Loamy subsoil: texture as in type
C = Clayey subsoil: texture as in type
R = Rock or other hard root restricting layer

CONDITIONER MODIFIERS:

In plowed layer or 20 cm (8 in.), whichever is shallower, unless otherwise specified ( )

*g = (gley): Mottles $\leq$ 2 chroma within 60 cm from surface and below all A horizons or saturated with H_2O for > 60 days in most years.

*d = (dry): Ustic or xeric environment: dry > 60 consecutive days per year within 20-60 cm depth.

e = (low CEC): < 4 meq/100 g soil by Σ bases + unbuffered Al.
> 7 meq/100 g soil by Σ cations at pH 7.
< 10 meq/100 g soil by Σ cations + Al + H at pH 8.2.

*a = (Al toxic): > 60% Al saturation of CEC by Σ bases and unbuffered Al within 50 cm.

> 67% Al saturation of CEC by Σ cations at pH 7 within 50 cm.

> 86% Al saturation of CEC by Σ cations at pH 8.2 within 50 cm or pH < 5.0 in 1:1 H_2O except in organic soils.

*h =	(acid):	10-60% Al saturation of CEC by Σ bases and unbuffered Al within 50 cm or pH in 1:1 H_2O between 5.0 and 6.0.
i =	(Fe-P fixation):	% free Fe_2O_3-clay > .20 or hues redder than 5 YR and granular structure.
x =	(X-ray amorphous):	pH > 10 in 1 N NaF or positive to field NaF test or other indirect evidences of allophane dominance in clay fraction.
v =	(Vertisol):	Very sticky plastic clay, > 35% clay and > 50% of 2:1 expanding clays. COLE > 0.09. Severe topsoil shrinking and swelling.
*k =	(k deff):	< 10% weatherable minerals in silt and sand fraction within 50 cm or exch. K < 0.20 meq/100 g or K < 2% of Σ of bases, if Σ of bases < 10 meq/100 g.
*b =	(carbonate):	Free $CaCO_3$ within 50 cm (fizzing with HCl) or pH > 7.3.
*s =	(salinity):	> 4 mmhos/cm of saturated extract at 25^o within 1 m.
*n =	(sodic):	> 15% Na saturation of CEC within 50 cm.
*c =	(cat clay):	pH in 1.1 H_2O < 3.5 after drying: Jarosite mottles with hues 2.5 Y or yellower and chromas 6 or more within 60 cm.

Source: S.W. Buol, P.A. Sanchez, R.B. Cate Jr. and M.A. Granger 1975: 'Soil fertility capability classification'. A technical soil classification for fertility management. pp.126-141. In: E.Bornemisza and A.Alvarado (Eds.): Soil Management in Tropical America, North Carolina State University, Raleigh.

land quality - output relations in supporting input - output analysis. How refined such ratings of IQD and IQ should become will depend on how the responsiveness to inputs varies in the study area and on the urgency for the value of IQ to be established.

The most obvious urgencies arise because of the scarcity and cost of certain inputs: transport prices; labour costs; scarcity of water and fossil energy resources; or from environmental considerations, e.g. the cost of recycling polluted drainage water.

Since it is difficult to express IQ values quantitatively, simple ratings that only distinguish between a few levels of response to inputs for land improvement on an ordinal ranking scale (land units with a very high - high - medium - low responsiveness for the input in question) could contribute significantly to the deductive stage of land evaluation, especially when the assumptions on which such a ranking is based are expressed in terms of values of land improvement quality determinants (see Fig. 3.3).

With the growing understanding of the underlying fundamental processes that control the input-land quality relations and the input-output relations it may be expected that the analysis of (I, LQ) relations and the estimation of the value of the parameter IQ could become more and more a matter of logical reasoning based on fundamental cause-effect relations and less of empirical correlation.

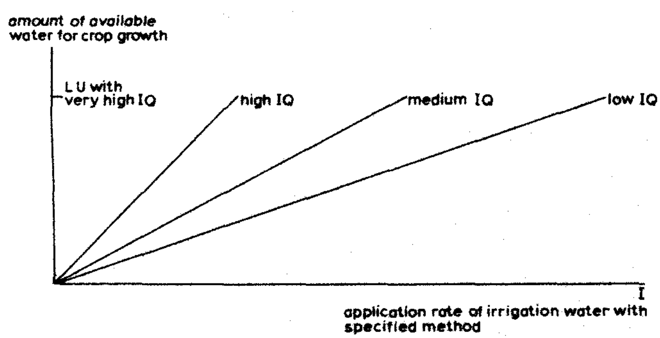


Fig.3.3: Ordinal ranking of the parameter IQ: responsiveness of the land to inputs for partitioning land (mapping) units into populations with different water application efficiencies.

Are IQ values always constants?

IQ values are determined primarily by land improvement quality determinants that are difficult to change, e.g. the texture of the soil and its permeability, soil depth, slope, gradient. In reality the parameter values of IQ are not entirely immutable. For example, the response to fertilizers is affected by the cation exchange capacity of the soils. If the soil is going to be irrigated, this can result not only in a change in the land quality 'water availability', but also in a change in the organic matter content; either a decrease possibly resulting in an even more constrained response to fertilizers, or an increase, which affects the response to fertilizers favourably. Sometimes the side-effects of physical inputs on the land and on its responsiveness to other inputs can be quite unexpected, and should therefore be of major concern during land evaluation.

Sometimes inputs are applied with the explicit purpose of changing the responsiveness of the land to inputs. In some of the Arab countries, where water is a more expensive resource than oil, soil conditioners have been applied, for instance to increase the water retention capacity of the soil, or to decrease its susceptibility to wind erosion. Although rare, these countries can make use of a large supply of cheap waste and by-products of the petro-chemical industry to tackle the problems of a too low responsiveness to inputs. It is more common that the responsiveness to inputs is gradually improved as a side-effect of the application of inputs to correct limiting land qualities, such as the application of organic manures on infertile land, resulting in better soil structure, input response etc. At the same time, the input-producing industries continue their research towards producing more efficient products to cope with low conversion efficiencies resulting from the low IQD and IQ values that have been observed. An example is the development of slow-release fertilizers, which can be used efficiently when the land improvement qualities IQ for normal fertilizer applications are low.

Parametric methods

The usefulness of the methods described to measure land qualities quantitatively can be attributed in no small measure to the small number of limiting factors taken into account: susceptibility to erosion, the available water, the available oxygen, the natural soil fertility. A distinction must be made between quantitative methods in land evaluation that concentrate on specific land qualities, as has been discussed so far, and those methods that attempt to include all land factors influencing the performance of a land use system simultaneously in a quantitative analysis. The latter methods are known as 'parametric' methods in the literature. They have been most concerned with rating the 'super' land quality 'productivity'.

The first demand for such methods arose from the need for objective quantitative standards in raising land taxes. The Storie-index (Storie, 1937, 1950) was developed for this purpose. An example of combining values of a variety of characteristics (soil texture, parent rock, natural soil fertility level) into a rating for taxation purposes in the Federal Republic of Germany (Taschenmacher, 1954) has been cited by Vink (1975). Nowadays parametric methods are also employed for purposes of land use planning. An example is the use of parametric methods for calculating target yields for state farms in Eastern European countries (e.g. Teaci, in FAO, 1974; Krastanov *et al.* in FAO, 1975b) and the methods published by FAO for the prediction of biological productivity (Riquier and Bramao, 1964; Riquier, 1974). According to Riquier (in FAO, 1974a, p.74) the parametric method consists of:

(1) evaluating separately the different properties of soils and giving them separate numerical valuations according to the importance within and between each other,

(2) combining these factors (numerical values) in a mathematical law[1]) taking into consideration the relationships and the interactions between the factors to produce a final index of performance,

(3) which in turn is used to rank soils in order of agricultural value.

---

[1] *'law' is too strong a word for such an empirical equation; mathematical expression' is better.*

Each factor has an influence on the final result according to its own equation, other factors being considered constant. The combination of factors to include their interactions may be either additive, additive and subtractive, multiplicative, or a more complex equation:

$$P = C'k + C''l + C'''m \qquad (1)$$

$$P = C'k + C''l - C'''m \qquad (2)$$

$$P = C'k \times C''l \times C'''m \qquad (3)$$

$$P = A\,(C'k + C'''m)/C''l \qquad (4)$$

P = production in kg/ha

k.l.m = production factors, e.g. soil depth, texture

A = constant

C',C'',C''' = coefficients giving appropriate weights to the individual production factors

Riquier (in FAO, 1974) observes that the multiplicative method is realistic and conforms to experimental data. After presenting some advantages and disadvantages, Riquier (in FAO, 1974a, p.52) concludes that:

> the parametric method provides an attempt to express land evaluation in quantitative terms compatible with modern facilities for calculation. It introduces quantitatively the use of yield and productivity in a manner which provides communication between the pedologist and the economist. It can easily be integrated with other global methods of land classification to provide an evaluation of the agricultural value of the soil.

Parametric methods have mainly been based on easily measurable properties of the land, not on land qualities, and consequently there is a likelihood that interactions (and therefore site-specific conclusions) exist, thereby preventing analogies being made. Parametric methods represent empirical methods of land use systems analysis; the land use system is treated as a black box, little attention is paid to its internal structure and to the functional relations between inputs, land qualities and outputs.

However, with statistical methods of analysis, high coefficients of correlation have sometimes been found between the soil and climatic parameters and, for instance, yield, although the number of land parameters considered is rather limited, as are the inputs considered. Parametric methods have been more concerned with predicting biological output than with the role of inputs or the effect of land utilization on the status of the land qualities.

Advocates of parametric methods have sometimes criticized supporters of more qualitative methods for being subjective in their treatment of the selected variables influencing the land suitability classification or the land productivity rating.

However, as Burrough (1976) has observed, though the mathematical treatment of factors in parametric methods gives them the appearance of objectivity, the selection and compounding of factors is still largely a matter of choice. The subjective aspects of parametric methods are reduced if the factors used reflect the results of field trials and if the results have statistical significance. Parametric methods still lack adequate treatment of biotic and climatic controls. Once all important factors have been identified the use of complex modelling techniques should improve the ability of the parametric approach to calculate the relations between all the significant production factors and productivity.

Temporal and spatial variation of land qualities

Land qualities may vary in space and time. Consequently, when observing and measuring land qualities and component properties, the arbitrary disaggregations of the land resource continuum must be considered in the context of space and time. The temporal variation is the result of weather-imposed and human influences. Because of the temporal variation, land resources studies may need to take heed of different time perspectives, ranging from the variation within one crop or rotation growing season, to the variation that may occur during the period considered by long-term (20-40 years) perspective studies for development. Spatial variation refers to the variation of the values of land qualities and component properties both horizontally and vertically.

The horizontal disaggregation of land into component qualities and properties is the object of land resource surveys and depends on such factors as: purpose of study; feasible density of observations; availability of financial resources, human resources, aerial imagery, topographic maps; the heterogeneity of each property/quality; skill of the surveyor; data processing facilities; etc. (UNESCO, 1965; Zonneveld, 1972; Mitchell, 1973; Nossin, Ed., 1977).

By virtue of their location in the landscape, land (mapping) units often share the same geomorphological processes of transfer of mass. For example, land units lying in the catchment of one river system may be linked sequentially downstream by the water flow of that river and will therefore experience effects that have originated on other, not necessarily adjacent, land units (e.g. sedimentation, flooding, salinization). To explain and predict such interactions between land units, data collection needs to be aware of the general geomorphological setting. The systems approach to geomorphology has been discussed by Chorley and Kennedy (1971; see also Section 3.3.2 and Chapter 5 of this report).

The vertical disaggregation of the land into different strata to facilitate data collection should also consider the interactions between these strata caused by flows of mass and energy. Perhaps the most obvious disaggregation, which corresponds roughly to the subdivision between disciplines traditionally engaged in data collection is:

1. OFF-GROUND, the atmosphere above the vegetative cover (macro-climate)
2. NEAR-GROUND, the vegetative cover and the atmosphere in this cover (micro-climate)
3. GROUND SURFACE, the borderline between atmosphere and soil
4. SOIL
5. SUB-STRATA, the deeper strata below the soil

Each stratum can be further disaggregated into composing substrata, layers, or horizons for the purpose of land evaluation.

The five strata, product of vertical disaggregation, vary areally too. In small-scale land evaluation, the areal variation of meteorological variables will strongly affect the delineation of boundaries between land (mapping) units. In intermediate and detailed land evaluation the soil and surface conditions will provide many of the boundaries. Sub-strata conditions greatly influence land evaluations that include the consideration of irrigation and drainage.

The temporal variation of land qualities and component properties also needs to be taken into account. To achieve this, their values should be measured during significant time periods or at time-discrete moments. The timing of land use activities and processes, (i.e. the cropping calendar) determines how the finite time periods for observing and measuring land qualities and properties must be chosen. For example, the time periods may correspond with the time-specific requirements of the land utilization types for land preparation, sowing, germination, early vegetative growth, etc. Relating these land use activities and processes to the land qualities and component properties should indicate which qualities and properties need careful examination, and at what time of the year, the month, the week or even the day.

It is not easy to measure time-variable land qualitites and properties. We may have to go to great lengths to be able to characterize a non-steady state regime, e.g. by constructing an analog simulation model of the non-steady unsaturated flow of moisture in the soil (Wind, 1976) to characterize the moisture tension and related workability of the topsoil during springtime in the Netherlands.

The dynamic fluctuations of the values of land qualities and component properties produce a characteristic pattern for each stratum, e.g. the daily, weekly and seasonal temperature and moisture fluctuations.

Temporal disaggregation will be further discussed in the next section (3.2.) which deals with the disaggregation of land utilization types and identification of land requirements.

3.1.3 Land qualities and land resource data collection

Data collection is, perforce, a selective process. The mono-disciplinary collection of data to characterize land attributes and land properties has traditionally paid much attention to the aspects of genesis and classification, particularly in soil survey. Interpreting such data for the solution of land use problems usually requires a more complex body of information than can be provided by a mono-disciplinary approach orientated towards single attributes. For example, the interpretation of soil surveys for agricultural uses requires cross reference to data collected by meteorologists, hydrologists, etc. Even the study of one land attribute, such as soil, is often partitioned into specializations susceptible to communication problems, e.g. between soil survey, soil fertility research and soil conservation studies.

The land utilization type concept is expected to provide common ground for these various disciplines and specializations and can make their studies more problem-orientated. As far as collecting land resources data to characterize land qualities is concerned, even in reconnaissance soil survey the main land use problems and development options are recognizable. Instead of standardized data collection for a high category of soil classification, it should be possible to collect some additional data such as infiltration capacity of sloping land occupied by traditional farmers, hydraulic conductivity of poorly drained bottom-lands,pF values, data about aggregate stability, etc. Indeed, reconnaissance soil survey in Brazil includes collecting compound samples for soil fertility analysis. However, few soil survey manuals deal with specific purposes: the draft edition of a new soil bulletin of FAO on soil survey investigations for irrigation is an exception (FAO, 1974b).

When collecting land resource data to solve the land use problems of farmers or other land users we must be fully aware of the farmer's land-dependent activities. We should be able to concentrate on the fundamental processes and activities of the specific land utilization type and the role of measurable land qualities/properties in these processes.Is this feasible? This depends on our interpretation of the term fundamental. For a biologist (PUDOC, 1970; de Wit & Goudriaan, 1974), photosynthesis, respiration and transpiration are fundamental processes. He may try to simulate, for instance, plant root growth as a function of variables such as soil temperature and soil oxygen, measured hourly or daily. Such precision may be possible in a programme of meteorological data collection but not in a soil survey. On the other hand, parametric methods that translate a set of measurable soil properties directly into expressions of productivity or suitability, based on statistically-found correlations pay little attention to the underlying fundamental processes. A balance must be struck between these two extremes.

In its effort to construct sophisticated analog and computer simulation models, research sometimes forgets that some concrete analog models may still be found in nature; the natural vegetation and present land use can reveal much of how hypothetical land use alternatives may be expected to perform. A good example from Brazil is the interpretation of the natural forest vegetation in terms of water availability: Beek and Olmos (1964) prepared land suitability maps for cocoa production in coastal Bahia, making a direct correlation between the water requirements of cocoa and features of the tropical forest vegetation that express the land quality 'water availability'. To permit this the reconnaissance-type soil surveys in Brazil include the natural vegetation as a phase in the soil (mapping) unit (Bennema and Camargo, 1963).

Another example is the use of the natural vegetation as an indicator of soil permeability and soil salinity (Risseeuw, 1972). The soil surveyor is in the exceptional position of being able to observe and correlate such phenomena to refine the prediction of soil behaviour under specific uses.

Conclusion

The systematic disaggregation of land in terms of land qualities is in its early stages of development. If the concept of land qualities can be developed successfully, it could serve several purposes:

- indicating which land properties deserve priority for study in land resources surveys;

- systematizing the soil surveyor's capacity to observe and interpret natural phenomena: levels of some land qualities can be deduced directly from the present land use. Crops and natural vegetation provide a model for the optimal land use systems as far as ecological processes and related ecological land qualities are concerned (Bennema, 1976);

- facilitating knowledge transfer to areas in developing countries with a poor data base for optimizing land use, because land properties with a site-specific influence on land use performance are synthesized into land qualities controlling fundamental land use processes and therefore of broader application than single properties;

- Improving the predictive value of land suitability classifications and the possibility of their periodical updating.

3.2 Disaggregation of land utilization types and the identification of land requirements

In previous chapters the procedure for defining land utilization types has been discussed and their key attributes have been described. Given this background it should be possible to identify the specific land requirements of each land utilization type, but this is complicated because the land use process is continuous and dynamic. Therefore, to facilitate data measurement and manipulation it will be necessary to disaggregate the land use process into a number of component processes and activities that take place during defined time periods. Each process or activity should be characterized by its own land requirements. During these finite time periods the land requirements may be assumed to be constant, to simplify the task of land evaluation. Once the continuous land use process has been disaggregated into a kind of land utilization calendar which specifies in chronological order each pertinent land use process/activity and the corresponding land requirements, it should become possible to make a problem-orientated analysis of the status of the time-variable land qualities that should meet these land requirements. This calendar will also be useful for ascertaining the optimal application of physical inputs for improving and maintaining the land qualities.

The list below gives examples of time-discrete sub-processes and activities produced by disaggregating the continuous land use process.A distinction has been made between plant growth and plant development (Rose, 1969). Growth is the increase in plant material (if possible, differentiated for the various parts of the plant: roots, stem, leaves, generative part). Development is the sequence of phases throughout the crop cycle which relate to changes in form and structure, such as germinative, vegetative and reproductive phases. Some land variables seem to have a so-called 'trigger action' effect on plant development, such as soil moisture and soil temperature on germination. Day length and temperature are also known to affect the initiation of other development phases, for example, for flowering.

Fitzpatrick and Nix (1970) mention three distinctive thermal response curves for tropical grasses, tropical legumes and temperate grasses and legumes. The differences between them have been attributed to a trigger-action effect.

A land evaluation procedure that takes into account each biological production process and every agricultural activity concerned with land management, improvement and conservation is unlikely to be operational soon, in view of the great number of processes, variables and relationships involved. The ability of plants and animals to adapt to constraining land conditions makes it even more difficult to predict agricultural land use performances. However the literature on dynamic modelling and simulation of ecological processes and plant growth is increasing rapidly as more of the underlying plant growth processes are understood and the possibilities of mathematical data processing grow (e.g. Patten, 1971, 1972; PUDOC 1975-1977). The Elementary Crop Growth Simulator, ELCROS, of de Wit *et al.* (1971, 1978) is a pioneering example of how a data-analysis based on fundamental land use processes should ideally operate. Of course, practical land evaluation is still limited to less sophisticated simulations of the processes and activities that will result from a certain land utilization type being combined with different land (mapping) units.

Because of the complexity of the land use process, analog and mathematical simulation models usually refer to partial processes that take place during finite time periods and that are related to a particular limiting land quality. An example is the time-finite activity 'land preparation' which is related to the land quality 'workability' and depends on the seasonally varying characteristics of component properties such as the groundwater table, infiltration rate, pF values of the topsoil, rainfall and evaporation, data, etc. (Wind, 1976).

Recognizing the need and possibilities for using partial simulation models to solve land use problems, Nix (1968) has suggested that for a first assessment only energy, water and plant nutrients should be considered and that other 'regimes' (= land qualities) should be assumed not to be limiting. This may be a good solution for Australian land conditions, but for land evaluation in general, *a priori* elimination of any land quality that may not satisfy the land requirements of the utilization type is premature.

To streamline data-collection and to sharpen its focus on the most elementary land-use bottlenecks, the early stages of land evaluation could be improved by consulting a matrix that relates the various land use processes and activities to the land qualities and their component properties, and the strata in which they should be measured (see Table 3.3).

LP - Land Preparation

SO - SOwing or planting

FE - FErtilization, manuring

IR - IRrigation (water application, maintenance)

DR - DRainage (water management, maintenance)

PP - Phytosanitary Practices

GE - GErmination

AP - Asexual Propagation (cropping, budding, cutting: stem, roots, bulbs, tubers)

VD - Vegetative Development

- VDR - root development
- VDS - stem development
- VDL - leaf development

VGL - Early Vegetative Growth

- VGER - Early Vegetative Root Growth
- VGES - Early Vegetative Stem Growth
- VGEL - Early Vegetative Leaf Growth

VGR - Rapid Vegetative Growth

- VGRR - Rapid Vegetative Root Growth
- VGRS - Rapid Vegetative Stem Growth
- VGRL - Rapid Vegetative Leaf Growth

GD - Generative Development

- GDS - Generative Development, Sexual
  - GDSF - Production of flowers and embryo, apomixia
  - GDSS - Fruit and Seed development
  - GDSR - Ripening and dissemination of seed
- GDA - Generative Development - Asexual: buds, layering, bulbs, tubers ... etc.

HA - HArvesting

SV - SurVival (perennials)

FA - FAllow (rotations)

LAND QUALITIES (LQ)	MEASURABLE COMPONENT QUALITIES/ PROPERTIES (CP)	STRATA IN WHICH LQ & CP ARE TO BE MEASURED	TIME DISCRETE LAND UTILIZATION PROCESSES AND ACTIVITIES[1] DURING t_1, t_2, ... t_{24}																							
											VG															
											VD			VGE			VGR			GDS						
			LP	SO	FE	IR	DR	PP	GE	AP	R	S	L	R	S	L	R	S	L	F	S	R	GDA	HA	SV	FA
			t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}	t_{21}	t_{22}	t_{23}	t_{24}
e.g. FERTILITY	nitrogen phosphorus potassium calcium	e.g. topsoil 0-20 cm			+ ++ ++ ±																					
TOXIC ELEMENTS																										
WATER																										
OXYGEN																										
TILTH																										
FOOTHOLD																										
WORKABILITY																										
EROSION etc.																										

TABLE 3.3: MATRIX for the identification of land qualities (LQ) and component qualities/properties that need to be measured for a problem-orientated land evaluation. The squares may be filled in to indicate the need for the mentioned data by using the following symbols (example):

++ = much needed   + = needed   ± = desirable   - = not needed

1 for explanation of symbols see list of activities in Section 3.2.

Measurement of land requirements

Much is already known about the values of LR as far as the land requirements of specific crops are concerned, e.g. on the nutrient and water requirements, resistances to toxic elements such as alkalinity and salinity (e.g. Table 3.4, adapted from Ayers and Westcott, 1976 by Doorenbos and Pruitt, 1977; Slabbers and Herrendorf, 1977; de Geus, 1967).

Fig. 3.4 presents four regression lines. Each line expresses the LQ-Y relation of a land utilization type (crop) with a different land requirement (LR_s) for the land quality (LQ_s) 'absence of soil salinity'. The regression lines could be represented by the following discontinuous linear function:

$$Y_{(\text{relative yield})} = 100 - b\,(LQ_s - LQ_{s\ \text{critical}})$$

$$Y = Y_{max} = 100\% \text{ for } LQ_s \geq LQ_{s\ \text{critical}}$$

in which:

- Y = percentage yield for the land (mapping) unit in question
- LQ_s = land quality 'absence of soil salinity' expressed in terms of EC_e values: Electrical Conductivity of the saturation extract of the soil in millimhos per cm at 25° C.
- $LQ_{s\ \text{critical}}$ = lowest land quality value (or highest EC_e value) at which no reduction is caused in yield by soil salinity
- b = slope of function, expressed in percentage yield/mmhos

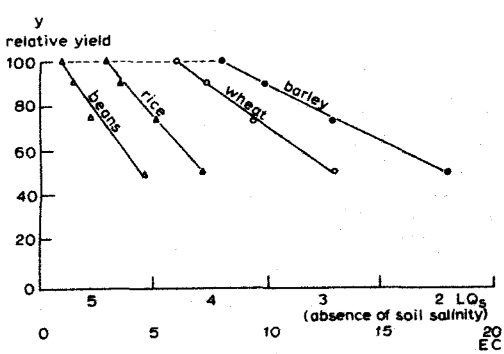


Fig.3.4: Functional expression of land quality-output relations for four land utilization types (crops) with different land requirements Y=F (LQ_s,LR). Adapted from: Ayers & Westcott, 1976; see also Table 3.4.

For reasons of simplification a discontinuous linear function has been fitted to the data points expressing LQ_s,Y values. Quadratic and exponential functions are also quite common, as are logarithmic functions for expressing LQ-Y and I-Y relations.

The function could also be presented in terms of absolute yield, rather than in relative yield:

$$Y_{(absolute)} = Y_{max} - b(1Q_s - LQ_{s\ critical})$$

$$Y_{(absolute)} = Y_{max} \text{ for } LQ_s \geq LQ_{s\ critical}$$

Fig 3.4 indicates that b (the value of the land requirement LR) takes a value that depends on the critical level $LQ_{s\ critical}$ at which the land conditions begin to limit the output, and the slope indicating the direction or velocity with which the yield decreases with increasing soil salinity.

Parameter values of land requirements, summarized by the symbol LR, but as indicated in Fig.3.4 composed of a critical level $LQ_{s\ critical}$ and the slope b, can be determined with the help of curves fitting the equation Y = F (LQ, LR). But the fitting of such curves requires that a number of data points correspond with observed and measured values of (LQ,Y) combinations for specific land utilization types. This information is not always available, certainly not for every (LUT, LU) combination that is considered to be important in the study area. On the other hand, evaluation cannot always wait until the required site-specific research-tested information has been produced. Therefore other approaches for obtaining this vital information are needed, the most obvious one being the transfer of knowledge from analogous situations that are better known. Reference has already been made to yet another approach: the use of simulation models. In fact some authors (Sanchez, 1976; Keller *et al.*, 1973) have expressed their concern at the amount of site-specific research on input-output relations that is duplicated on fertilizer response and water management, without making sufficient use of transfer of knowledge. Using analogy would require published results to be made very specific in their description of the factors (particularly in the description of land conditions, plant materials and physical inputs) that underlie the results.

Table 3.4. Crop Salt Tolerance Levels for Different Crops

Crop	Yield potential								Max.ECe
	100%		90%		75%		50%		
	ECe †	ECw	ECe	ECw	ECe	ECw	ECe	ECw	
Field crops									
Barley [1]	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28
Beans (field)	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	7
Broad beans	1.6	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12
Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Cotton	7.7	5.1	9.6	6.4	13.0	8.4	17.0	12.0	27
Cowpeas	1.3	0.9	2.0	1.3	3.1	2.1	4.9	3.2	9
Flax	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Groundnut	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	7
Rice (paddy)	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	12
Safflower	5.3	3.5	6.2	4.1	7.6	5.0	9.9	6.6	15
Sesbania	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	17
Sorghum	4.0	2.7	5.1	3.4	7.2	4.8	11.0	7.2	18
Soybean	5.0	3.3	5.5	3.7	6.2	4.2	7.5	5.0	10
Sugarbeet	7.0	4.7	8.7	5.8	11.0	7.5	15.0	10.0	24
Wheat [1]	6.0	4.0	7.4	4.9	9.5	6.4	13.0	8.7	20
Vegetable crops									
Beans	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	7
Beets [2]	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15
Broccoli	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14
Cabbage	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12
Cantaloupe	2.2	1.5	3.6	2.4	5.7	3.8	9.1	6.1	16
Carrot	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.1	8
Cucumber	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.2	3.4	9
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	8
Pepper	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	9
Potato	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Radish	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	9
Spinach	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15
Sweet corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10
Sweet potato	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	11
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13

Crop	Yield potential								Max.ECe
	100%		90%		75%		50%		
	ECe[†]	ECw	ECe	ECw	ECe	ECw	ECe	ECw	
Forage crops									
Alfalfa	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16
Barley hay [1]	6.0	4.0	7.4	4.9	9.5	6.3	13.0	8.7	20
Bermuda grass	6.9	4.6	8.5	5.7	10.8	7.2	14.7	9.8	23
Clover, berseem	1.5	1.0	3.2	2.1	5.9	3.9	10.3	6.8	19
Corn (forage)	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	16
Harding grass	4.6	3.1	5.9	3.9	7.9	5.3	11.1	7.4	18
Orchard grass	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4	18
Perennial rye	5.6	3.7	6.9	4.6	8.9	5.9	12.2	8.1	19
Soudan grass	2.8	1.9	5.1	3.4	8.6	5.7	14.4	9.6	26
Tall fescue	3.9	2.6	5.8	3.9	8.6	5.7	13.3	8.9	23
Tall wheat grass	7.5	5.0	9.9	6.6	13.3	9.0	19.4	13.0	32
Trefoil, big	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	8
Trefoil, small	5.0	3.3	6.0	4.0	7.5	5.0	10.0	6.7	15
Wheat grass	7.5	5.0	9.0	6.0	11.0	7.4	15.0	9.8	22
Fruit crops									
Almond	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.7	7
Apple, pear	1.7	1.0	2.3	1.6	3.3	2.2	4.8	3.2	8
Apricot	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	6
Avocado	1.3	0.9	1.8	1.2	2.5	1.7	3.7	2.4	6
Date palm	4.0	2.7	6.8	4.5	10.9	7.3	17.9	12.0	32
Fig,olive,pomegr.	2.7	1.8	3.8	2.6	5.5	3.7	8.4	5.6	14
Grape	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12
Grapefruit	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8
Lemon	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8
Orange	1.7	1.1	2.3	1.6	3.2	2.2	4.8	3.2	8
Peach	1.7	1.1	2.2	1.4	2.9	1.9	4.1	2.7	7
Plum	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.8	7
Strawberry	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4
Walnut	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8

1 *During germination and seedling stage ECe should not exceed 4 or 5 mmhos/cm. Data may not apply to new semi-dwarf varieties of wheat.*

2 *During germination ECe should not exceed 3 mmhos/cm.*

† *ECe means Electrical Conductivity of the saturation extract of the soil in millimhos per cm at 25 °C.*

ECw means Electrical Conductivity of the irrigation water in millimhos per cm at 25 °C.

Source: adapted from Ayers and Westcott, 1976, cited in Doorenbos and Pruitt, 1977, p.78.

3.3 Internal and overall land suitabilities

3.3.1 Major landscape elements and overall land qualities

In endeavouring to simplify the concepts of land qualities and land requirements in previous chapters, the impression may have been created that their sole purpose is to determine the suitability of individual land (mapping) units and the specific land utilization types operating on these land units. Although land evaluation often limits itself to this kind of land suitability classification, it is sometimes necessary to carry out land suitability classifications that take into account landscape elements of a higher order, composed of several land (mapping) units.

Systematic resources surveys normally pay attention to the general composition of the study area, recognizing landscape elements at different levels of generalization. Individual land units usually correspond with the most detailed subdivision of such landscape elements. Geology, geomorphology, climatology, hydrology and physiography are normally described in such a way that the principal landscape elements and their relations with individual land units can easily be recognized. Aerial photograph interpretation and resource mapping techniques often begin by identifying and subdividing such broad landscape elements. Of course these landscape elements can also present certain 'overall' characteristics, qualities or limitations, comparable with the more 'internal' characteristics, qualities and limitations of individual land units.

Examples of 'overall' land qualities of major landscape elements are: the distribution of water wells and the location of a river in a semi-arid grazing area (e.g. of the Sahelian type); the precipitation, interception and water storage capacity as agents of the hydrological cycle and water flow in a catchment; the way the vegetative pattern regulates climate by influencing the movement of cold airmasses in an area of frost hazards; the presence of a water storage basin on the border of an area with potentially fluctuating groundwater tables (e.g.the Veluwe lake, on the divide between the IJsselmeer polders and Pleistocene uplands in The Netherlands; Volker et al., 1969) presence and location of basins for temporary water storage and flood control (e.g. Cienagas of Magdalena river system in Colombia); the presence of low-lying land reserves suitable for discharge and evaporation of saline drainage water; the quality of irrigation water at the inlet of an irrigation district; the gradient between the water inlet and the water outlet of an irrigation and/or drainage project.

A land evaluation that takes account of major landscape elements and their overall land qualities can help solve two very complex land use planning problems:

- the analysis of land use interactions
- the assessment of the impact of full-scale implementations of the land use proposals

3.3.2 Land use interactions

Land (mapping) units rarely coincide with landscape elements. This must be borne in mind when considering cause-effect relations between land units, because the major geomorphological processes operating over (and uniting) the whole landscape element may affect the component land units. Land use effects that are felt outside the land unit where they originate are sometimes not foreseen when land use recommendations are made. But they are most important. For example: a land unit in the lower part of a coastal plain seems to have the right land qualities for growing sugar cane, providing the groundwater table can be lowered. However, in the upper part of the plain sugarcane is grown very inefficiently, using too much irrigation water; this causes the high groundwater tables, salinization and workability problems near the coast. If the land suitability classification of the land unit in the lower plain does not consider the upper plain, it may be concluded that sugarcane can be grown, provided that a subsurface drainage system is installed to control the groundwater table. But a land suitability classification that views the lower plain in its context as part of a major landscape element - the coastal plain - may conclude that sugarcane production in the lower plain is feasible with a much simpler drainage system, provided that certain recommendations for more efficient water use in the upper plain are implemented.

Sometimes land evaluation will concentrate on land units in the upper catchment and will ignore the effects of land use changes on the lower catchment, or even on land use in areas that are not included in the same major landscape element. This is the case when large-scale implementation of settlement projects results in natural forests being replaced by pasture land and crops, thereby affecting the micro-climate and possibly even the macro-climate. Although the impact of land use changes on weather conditions and climate is controversial, consideration of the off-site effects of land use changes should certainly be a matter of concern for land evaluation (Wendt, Ed., 1971).

3.3.3 Impact of full-scale implementation of land use proposals

To evaluate the effect of full-scale implementation of land use proposals, the sum of the land requirements of individual land utilization types must be compared with the corresponding overall land qualities. For this purpose the term 'overall land requirement' will be useful: it encompasses the sum of individual requirements made by the different land utilization types that operate simultaneously on different land units belonging to the same major landscape element.

The land requirements of individual land utilization types could be distinguished from the overall land requirements by the term 'internal' land requirements.

Examples of overall land requirements are: the overall requirements for drinking water of all livestock grazing on a major landscape element, compared with the overall availability of drinking water of that landscape element; the overall drainage requirements in an irrigation project, compared with the overall water storage and drainage possibilities of the land area to be occupied by the irrigation project.[1]

When overall land requirements are compared with overall land qualities, constraints may be identified, warranting a reduction in area where the land use proposals are to be realized. The following examples should be able to clarify this point:

- In several parts of South America (Andean Region, Southern Brazil), traditional land utilization types were able to occupy fertile sloping land in forest areas on a permanent basis without causing alarming soil erosion. Only small parcels of land were occupied, obeying an established pattern of rotations, including fallows and forest reserves. But once the percentage of occupied land exceeded a critical limit for the area as a whole, determined by the resistance to erosion of the major landscape elements of which the land units are a part, land degradation accelerated, often with disastrous effects. Therefore land evaluation must include a prediction of erosion, based on the overall requirements for soil conservation of the envisaged land utilization types and the overall land quality 'resistance to erosion' of the major landscape element.

- In N. Parana (Brazil) there has been an intrusion of coffee plantations in areas marginal for coffee growing because of night frost hazards. Certain land units are traditionally protected from frost to a certain extent by nearby high-lying

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[1] *The comparison of overall land qualities with overall land requirements may necessitate very specialized scientific methods. Examples are hydrology and water management, which use elaborate methods to construct water balances and to plan and design irrigation and drainage systems. Another example is watershed management. This report does not presume to contribute to such established fields of specialization. The purpose of this study is to indicate how these specializations and the information they produce relate to the land evaluation concepts and procedures presented here, to assure better land evaluation results and closer cooperation with other specializations in the future.*

forested zones that prevent the cold air masses from moving into the coffee plantations. Removal of such forests would be disastrous for the coffee on lower lying land.Therefore land evaluation in such a zone, if contemplating coffee production, should take into consideration the overall land quality 'absence of frost hazard' of the major landscape element,including the possibilities for improvement, e.g. the creation of channels in the vegetation on the lower landscape element for the displacement of cold air masses, and of conserving the situation where frost is not limiting, according to the requirements for frost-free land conditions of the coffee-producing land utilization type (Camargo A.de,1966).

Field check on environmental impact

Vink (1975, p.316) proposes a field check after the provisional evaluations have been made,

> including the inspection of 10% or less of the area surveyed, to realize in the field the actual position in the terrain of the land mapping units which have been evaluated on the basis of maps and other data.

In my opinion such a fieldcheck will be most usefully served if the possible land use interactions and the impact on the environment upon full-scale implementation of the land use proposals are included.

There should be no doubt about the responsibility of the land evaluator to predict the environmental impact as precisely as possible. This has been done in the past by placing land units in a lower class when some doubts about the long-term effects of a particular land use existed. Often such a down-grading of the land (mapping) unit was merely intuitive, depending on the personal judgment of the land evaluation specialist. In a systematic land evaluation, the main variables influencing such environmental considerations should be explicitly mentioned. If the land utilization types are to receive more attention in land evaluation, their environmental impact should also be more precisely predicted.

Non-physical off-site effects of land use changes

So far our discussion has been limited to the physical effects to be expected from full-scale land use changes: the irrigation of arid lands, the occupation of hilly land with long slopes, the transformation of tropical forest areas into pasture land or crop land, the reclamation of lakes. But the non-physical effects, both on-site and off-site, of such land use changes can also be remarkable. Such off-site effects have also been described by the term 'ripple effects'. An example is the effect of the expansion (with government credit and subsidy) of the wheat and soybean acreage in S. Brazil on the labour situation. On-site there has been little increase in the number of farm labourers employed, but their productivity, real income and acquisitive power have increased substantially. Off-site the multi-million hectare increase of mechanized crop land, with its dependence on fertilizers, pesticides and other farm inputs has strongly influenced the services and manufacturing sector. Such socio-economic ripple effects are unlikely to affect the land suitability classification, unless these effects are included in the questions asked from land evaluation. This may occasionally happen in integrated land development projects. Although in most cases, they are not criteria, ripple effects can help determine the selection of relevant land utilization types and the adjustment of their definitions at an advanced stage of the land evaluation procedure, when the overall land requirements and the overall land qualities are compared and the resulting effects of the land use proposals are analysed. But the ripple effects must be of a certain magnitude before this is worthwhile.

Internal and overall land suitability classification

To distinguish between a land suitability classification with a narrow individual land (mapping) unit approach and one with a much wider environmental scope that takes into account major landscape elements, the terms 'internal' and 'overall' land suitability classification are proposed.

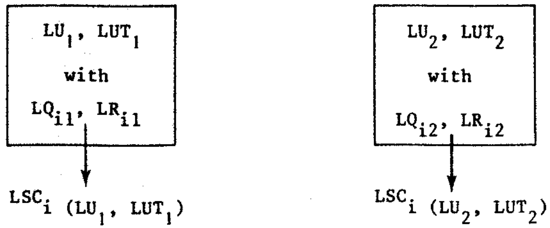
An internal land suitability classification

This is a classification of land (mapping) units according to the degree to which their internal land qualities meet the internal land requirements of a defined land utilization type, e.g. the listing of land (mapping) units according to their productivity when under a specific crop cultivated with a defined set of management practices.

An overall land suitability classification

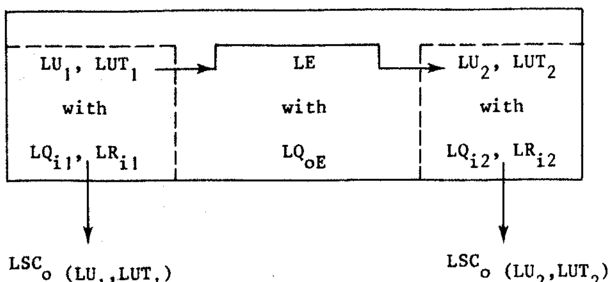
This is a classification of land (mapping) units and major landscape elements according to the degree to which their internal and overall land qualities meet the internal and overall land requirements. It takes into consideration the interactions between the envisaged land uses and an assessment of the environmental impact from full-scale implementation of the land use proposals.

This type of classification is unusual in today's land evaluation methodology. The USDA Land Capability System has been designed to minimize undesirable environmental impacts, but its methodology still needs considerable refinement to meet the standards of a true overall land suitability classification. Some recommended land use classifications, products of land use planning, also reflect some of the aims of the overall land suitability classification. However, they are mostly classifications in economic terms and may not be based on the kind of physical analysis suggested in this report.



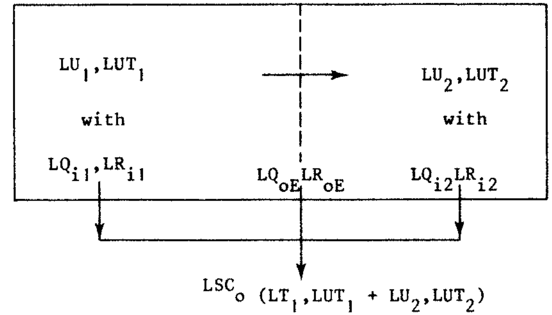
SITUATION 1

Internal land suitability classification of LU_1 and LU_2 for combination with LUT_1 and LUT_2 respectively



SITUATION 2

Overall land suitability classification of LU_1 and LU_2, part of LE, for combination with LUT_1 and LUT_2 respectively,taking into account the physical effect of (LU_1, LUT_1) on (LU_2,LUT_2), i.e.the interactions between (LU_1,LUT_1) and (LU_2,LUT_2)



SITUATION 3

Overall land suitability classification of LU_1 + LU_2, the constituent parts of LE, for full-scale occupation by combination with LUT_1 and LUT_2 respectively, taking into account the interactions between (LU_1, LUT_1) and (LU_2,LUT_2) as well as the physical effects of full scale implementation on LE with LQ_{oE} and LR_{oE}: environmental impact assessment

Explanation of symbols

LU land unit
LUT land utilization type
LE major landscape element
LSC_i internal land suitability classification
LSC_o overall land suitability classification

LQ_i internal land quality
LQ_o overal land quality
LR_i internal land requirement
LR_o overall land requirement

Fig.3.5: Relation diagrams for internal and overall land suitability classification.

Conclusion

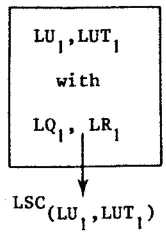
Land evaluation should be able to predict the impact of land use proposals not only for single land (mapping) units but also for combinations of land units and for the physical environment as a whole. Also, interactions occurring between different land uses operating on different land units should be foreseen. For this purpose a distinction is proposed between internal and overall land qualities, internal and overall land requirements, land (mapping) units and major landscape elements, internal and overall land suitability classifications. The relation diagrams, presented in Fig.3.5 summarize this proposal.

3.4 Combination of land utilization types

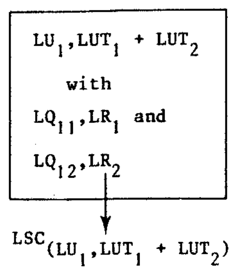
Sometimes land use planning has to consider combinations of land utilization types for the same land unit, or combinations of land units for the same land utilization type. It then becomes necessary to establish the principal combinations of land utilization types for land evaluation, and the position of land qualities and land requirements for combinations of land utilization types for land evaluation. At this point some definitions will be useful (see also Beek in FAO, 1975 a,b, and FAO, 1976):

- A 'single land utilization type' has land requirements that exclude other simultaneous uses of the land, e.g. large-scale sugarcane production.
- A 'multiple land utilization type' consists of more than one single land utilization type operating simultaneously on the same parcel of land, each with its own land requirements, inputs and outputs: e.g. recreation and timber production in the same forest area (Deshler, 1973; USDA, 1971b).
- A 'compound land utilization type' also comprises more than one single land utilization type operating on the same parcel of land but in different sites of the parcel. For the purpose or within the possibilities of land evaluation they constitute one use, with one set of land requirements: e.g. strip cropping, mixed cropping.

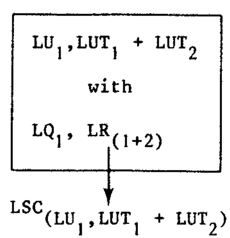
1. Single land utilization type



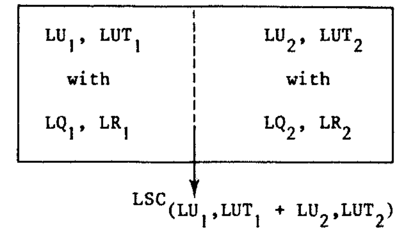
2. Multiple land utilization type



3. Compound land utilization type



4. Interacting land utilization types on inter-related land units



5. Land utilization type for combination of land units

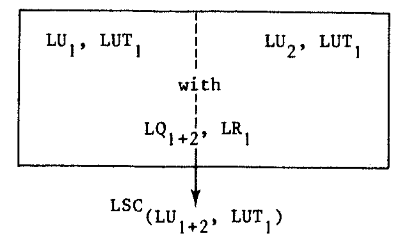


Fig.3.6. Relation diagrams indicating the role of land qualities and land requirements in land evaluations for combinations of land utilization types/land units.

- A land utilization type for a 'combination of land units' will be required when the constraining land qualities of the land units in question can be most conveniently met by combining them within one operational unit, e.g. the combination of seasonally flooded land with better-drained uplands for extensive grazing.

The position of land qualities and land requirements in a land evaluation for combinations of land utilization types and/or land units can be easily understood by studying Fig.3.6.

3.5 Availability and reliability of land resources data

At this stage of our discussion a few words need to be said about the available data base in land evaluation to explain some of the differences in methodology between practical land evaluation and the more theoretical approaches to land use and plant growth simulation mentioned in Section 3.2.

Land resources maps and the descriptions of land (mapping) units are products of land resources surveys. Land resources maps are produced either by superimposing maps displaying the properties of separate attributes of the land: the soil, the climate, the topography, etc., or by carrying out an integrated survey of the land attributes.

For purposes of land evaluation the land (mapping) units that are displayed on the maps are supposed to be homogeneous in their properties and qualities. But of course there will always be a certain degree of short-range variation unaccounted for. Land resources survey reports therefore need to include estimates of the purity/heterogeneity of the land (mapping) units and their properties. Classifications of land attributes and component properties underlying the maps and descriptions of land resources often take into account value ranges of diagnostic properties, e.g. the range in cation-exchange capacity, in base-saturation or in texture that corresponds to a particular classification category. This range may sometimes be too large, or the threshold values used for class distinction may not be relevant for the purpose of land evaluation.

Dijkerman (1974) referring to pedological data, distinguishes between observational and experimental data. Most pedological data are observational and the choice of data collected is subjective; the site and kind of data collected depend greatly on the pedologist's *a priori* hypotheses of what is important. Quantitative field and laboratory data may suggest a high degree of precision (the closeness of the measurements among themselves or their reproducibility), but their accuracy (the closeness of the measurements to the real value) can be questionable, especially when such data are extrapolated to bigger land units, e.g. data about hydraulic conductivity, soil fertility, salinity, etc. Obviously, the soil surveyor's competence affects the validity of his observations and maps. He chooses his sampling points purposely, not randomly, though the purpose as perceived by him may differ from the purpose of the user of the information.

Field observations need to be restricted to the most important information to enable the results to be produced within the allotted time and budget. Data collection is strongly conditioned by professional standards (e.g. guidelines for profile descriptions, soil survey manuals). Luning (1974, personal communication) concluded that in the low rainfall areas of Kapenguria, Kenya, the only feasible land utilization type was range management. Therefore, the soil survey scale, which had been established at 1:100 000 could be reduced to 1:250 000 for that area.

Land resource inventory specialists may have difficulty in satisfying all the users of their information to the same extent, whatever criteria they adopt for their classifications. This is apparent from some recent statistical studies of soil survey results. Webster and Butler (1976) found that simple correlations between morphological properties and other properties of the topsoil were almost negligible at Ginninderra Experimental Station near Canberra, Australia (an area known for its great heterogeneity). This partly explains the long-standing controversies between some soil survey and soil fertility specialists. Land evaluators should also recognize that the reliability of the data produced during the inventory stage poses limitations to the data analysis. It is sometimes useful to base interpretative methodology on ranges rather than on fixed values of measurable limiting land qualities and component properties. Webster (1977) has proposed the use of choropleth maps (maps that show area partitions) to indicate the limits within which relevant point data can be safely extrapolated, as a tool for land suitability classification. In view of the increasing use of computer-stored soil information, Webster also expects more use to be made of point symbol maps and isorithm maps (contour maps of continuous land variables such as soil thickness, texture, hydraulic conductivity) in detailed planning. Such maps provide great flexibility for expressing the spatial variation of land constraints and for analysing the response to inputs. However, the success of such new mapping techniques will depend on the extent to which they can be blended with the soil surveyor's capacity to observe and interpret natural phenomena in the field, and to make abstractions of the real situation by using the criteria and logic that underlie good soil classification systems. After all, data collection in land evaluation is not a statistical study based on stratified random sampling.

Homogeneity of land (mapping) units is sometimes considered a land quality: in The Netherlands, Pons (1977) has observed that the more homogeneous the land unit is, the more uniform its response to management will be, and therefore the easier an optimal utilization of the land will become. Homogeneity is also an important factor for the rationalization of agriculture: to increase the scale of operations the fields must be enlarged, which may require amalgamation of land areas of differing land qualities and management needs. Assessing the homogeneity of land units will always be a problem given the limitations posed by the sampling density. Observation of present land use and crop response sometimes help this assessment. Whatever methods of observation and data collection are chosen, one should always be on the look out for potential constraints for the uses in question. Observation of the present land use and discussion with the farmers are important, to improve the correspondence between the actual land conditions and the descriptions of the land units resulting from observing, measuring and classifying land resource properties. This need for correspondence between actual and described conditions stimulates the improvement of data collecting techniques and makes them more problem-orientated, thus improving our predictions of land behaviour and land use performance.

4. Approaches to land evaluation

To explain the land utilization type concept, references have been made to several methods of land evaluation used in different parts of the world. Apparently different methods of land evaluation have developed side by side, depending on the kind of land use problems to be solved and on the prevailing land conditions and constraints encountered. Also, the level of detail of field surveys and land resource mapping have had a strong influence on land evaluation methodology (Murdoch, 1972; McDonald, 1975; Brook, 1975).

Special attention will be given to land evaluation methods in Latin America, and to the role land utilization types play in these methods. Since this role may vary considerably depending on the approach to land evaluation employed, it seems necessary at this stage of our discussion to identify the main approaches to land evaluation. This chapter presents such a breakdown, and this breakdown should provide the necessary background for a more detailed discussion in Chapter 5, of the role of land utilization types in land evaluation. If the views expressed are not fully consistent with earlier contributions made to the *Framework for Land Evaluation* (Beek 1972, 1975a, 1975b FAO, 1976), explicit mention will be made. However, most of this part of the report provides complementary information for applying the *Framework for Land Evaluation* and the Soil Survey Interpretation Methodology actually employed by EMBRAPA in Brazil (Beek, Bennema and Camargo, 1964; Beek, 1975d).

Burrough (1976), when reviewing the major land evaluation systems of English-speaking countries, The Netherlands and the *Framework for*

Land Evaluation, makes a distinction between land evaluations that serve general purposes and land evaluations that serve specific purposes. General purpose land evaluation represents a standardized approach for all lands to evaluate their capability to support a generally defined land use. Examples are the USDA Land Capability Classification, and many local adaptations, for instance in Australia, New Zealand, Canada, England and Wales, Pakistan, Chile and many others.

Specific purpose land evaluation represents a pragmatic approach: not only the land but also the use possibilities are explicitly studied. Many soil suitability classification systems for specific crops belong to this category. General versus specific purpose land evaluation is probably the most fundamental subdivision as far as the role of the land utilization type in land evaluation is concerned.

In general purpose land evaluation, the land utilization type is a standardized, broadly defined kind of land use, which is not the subject of study during the land evaluation. In specific purpose land evaluation the land utilization type is not standardized but has to be selected in view of the prevailing physical and socio-economic conditions of the area where the land evaluation takes place. If all lands are evaluated on their suitability for the same land utilization type the classification has great comparative value, a major goal of general purpose land evaluation. If the lands are evaluated only for selected relevant land utilization types which are expected to be promising, the classification has more analytical than comparative value; specific purpose land evaluation. This report concentrates mainly on the role of land utilization types in specific purpose land evaluation.

In the *Framework for Land Evaluation* (FAO, 1976, pp.9-10), which is an example of specific purpose land evaluation, a distinction is made between a major kind of land use, which is 'a major sub-division of rural land use, such as rainfed agriculture, irrigated agriculture, grassland, forestry, recreation' and a land utilization type, which is 'a kind of land use described or defined in a degree of detail greater than that of a major kind of land use'.

Major kinds of land use correspond roughly with the broad standardized uses of general purpose land evaluation e.g. in the United States Land Capability System. The concept of land utilization type was introduced in the first place to support specific purpose land evaluation (Beek, 1972). It should be noted that specific purpose land evaluation does not refer exclusively to more detailed studies than the general purpose land evaluation. Both general purpose and specific purpose land evaluations may be carried out at any scale. The examples given in Section 4.3.4 of exploratory and reconnaissance land evaluation in Brazil are specific purpose land evaluations. The definitions of land utilization types may be very broad when describing one key attribute (e.g. agriculture versus pasture) but detailed in another key attribute (e.g. the level of capital intensity, or the kind of implements used). It appears to be difficult to make sharp distinctions between different levels of generalization when defining land utilization types, and therefore between a major kind of land use and a land utilization type.

When applying specific purpose land evaluation, it is essential to remember that the use is as much an explicit determinant of land suitability as the land itself, and that separate evaluations should be carried out for different uses. The level of detail at which the use is defined is of secondary importance. However, it is extremely important for the land evaluation methodology whether or not the use is specified beforehand, and also whether or not this methodology provides standardized information for translating the data collected about the land conditions into land classes. General purpose land evaluation is supposed to follow such a standardized methodology, while specific purpose land evaluation is more flexible, providing the land evaluator with an opportunity to consider most the most relevant types of land utilization, to determine their land demands and to interpret the degree to which the land conditions can meet these land requirements, i.c. the land suitability classes.

4.1 General purpose land evaluation

General purpose land evaluation follows a standardized procedure for all lands to evaluate their capability to support a generally defined land use. The suitability classification depends on relations between very broadly defined kinds of land use and qualities of the physical environment expressed in terms of limitations or hazards. A stable and near optimum mechanized management system is assumed. Technological and socio-economic variables are not considered. If one or more physical limitations can be removed, the same land capability classification with the same criteria applies, according to the limitations after improvement. To complement the broad definitions of land use, information about land management practices is presented in connection with the land capability units, which are subdivisions of the land capability classes with similar limitations and similar land management recommendations. There is no provision for comparison between the different kinds of land use. Agriculture is given precedence over pastoral, forestry and recreational or wildlife uses, respectively. On the other hand, all lands can be compared, once they have been classified according to the universal land capability classes.

The system of land evaluation is easy to understand, relates only to physical land variables and is relatively unaffected by social, economic or technological changes. Therefore the land classes remain valid for a long time. Land capability classifications at all scales can be easily set up, from the national to the farm level (soil conservation planning).

But the methodology also presents a number of disadvantages: these have led to the development of another approach - specific purpose land evaluation.

Disadvantages of the general purpose land evaluation are:

- Although intended to be of general purpose, the method is based on an understanding of the needs of only the most common land uses. In developing countries especially, the urgency of socio-economic development has created a need for land evaluation that takes into account more specific types of land use of local relevance. The broad development objectives of governments such as labour absorption, higher and more equal income and improved nutrition for a rapidly growing population require a pragmatic assessment of the prospects for more intensive land uses despite seriously limiting land resources.

- In many countries, present land use is very variable, corresponding to very unequal levels of technology. It will be difficult to predict land use performance on the basis of general purpose land capability classes.

- The system is not sufficiently specific for comparisons to be made between conflicting land uses, as it considers each use as a separate option. Though the system allows for the lands to be ranked according to how far they meet the requirements of several broad land uses, it does not provide a ranking of different land uses competing for the same parcel of land.

4.2 Specific purpose land evaluation

Specific purpose land evaluation also follows a standardized procedure but the methodology is not based on standardized relationships between pre-established uses and standard limitations of the physical environment.

Using all relevant and available physical, technological, social and economic data, each land area is evaluated on its fitness to support the most pertinent land utilization types. This fitness, or land suitability, is expressed in terms of the effects to be expected and the inputs required. Separate land suitability classifications are made for each relevant land utilization type. In a purely physical analysis, the effects or outputs are expressed in physical terms (erosion losses, yields) and the inputs are also expressed in physical terms (amounts of fertilizer, water applications, duration of field operations, labour requirements ...) quantified either on an ordinal or a ratio scale. In a physical analysis it is difficult to compare different uses that compete for the same tract of land, unless the multi-dimensional physical effects and inputs are brought under a common denominator: commensuration, or are grouped in capability/

suitability classes (see Sect.5.4)[1].

The most practical method of commensuration is by measuring all effects and inputs in monetary terms by applying appropriate prices. This usually requires some additional economic analysis.

The land evaluation methods employed by the United States Bureau of Reclamation, the ecological method of land evaluation of Beek and Bennema (1972) and the Framework for Land Evaluation (FAO, 1976) are examples of specific purpose land evaluation. These methods provide guidance for the physical and the socio-economic analysis. The soil survey interpretation system for reconnaissance surveys in Brazil (Beek, Bennema and Camargo 1964) covers only the physical analysis in specific purpose land evaluation.

Specific purpose land evaluation is complex and requires the services of different disciplines (soils, hydrology, water management, agronomy, agricultural economics, sociology, agricultural engineering):

- to select the relevant land utilization types
- to interpret the land utilization types in terms of specific land requirements
- to study the land conditions, determine the constraining land qualities and the possibilities of their improvement
- to predict the performance of the land use within defined levels of reliability, taking into account their land requirements and tolerances,
- to translate these predictions from multi-dimensional physical effects into common (mostly economic) terms.

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1 *The process of measuring factors of different dimension by the same standard, bringing them thus under one common denominator in systems analysis (Toebes, 1975) is referred to as commensuration. The best known commensuration is in monetary terms.*

A number of the disadvantages indicated for the general purpose land evaluation will thus be overcome; but several new problems emerge.

Outstanding are:

a) the greater dependence on precise information about fundamental cause-effect relationships between the constraining land qualities and the performance of the land use systems.

This problem, as a result of the many combinations that exist in the world between types of land utilization and types of land (constraints), has been the subject of innumerable fragmentary studies, mostly dealing with specific crops and rather site-specific physical land conditions.

Chapter 5 suggests ways of increasing the possibility of making analogy, despite of scarce specific local information, by using systems analysis and models in land evaluation.

b) The need for interdisciplinary cooperation. General purpose land evaluation has been mainly the task of soil scientists, who, with the help of comprehensive manuals of land capability classification, had little difficulty in assigning a land capability class - subclass-unit - to a particular land unit. They faithfully applied the rules and regulations of manuals, which in some places have acquired a sacred status.

Manuals for general purpose land evaluation have been published in consultation with agronomists and other specialists, but their contribution is usually rather generalized. The same may be said of the recommendations for environmental conditions of specific crops. References to soils are usually restricted to soils with no or few limitations: deep friable soils of high fertility, neutral pH, well drained, sufficient moisture and high organic matter. Such specifications do not answer the questions arising in most projects where the soils unfortunately seldom meet such qualifications.

Manuals could be prepared for specific purpose land evaluation. In fact, the documents prepared by the Working Group for the Interpretation of Soil Maps of The Netherlands Soil Survey Institute (Stiboka, 1976 Report No.6047) go in this direction,although the types of land utilization remain rather unspecific and as a consequence the corresponding critical levels of land qualities have not yet been elaborated in great detail.

Much has to be done, in developed countries too, to elaborate satisfactory guidelines for specific purpose land evaluation. Even the United States Bureau of Reclamation manual *Land Classification for Irrigated Land Use* (see also FAO, 1974b) is too broad a guide for specific purpose land evaluation. For a detailed land evaluation in relation to specific types of land utilization - say, horticultural crops and also for specific crop rotations - this manual gives no explicit guidelines on the interpretation of land conditions based on specific land requirements of the mentioned crops. Proper application of the United States Bureau of Reclamation system requires substantial support from agronomists, agricultural economists, agricultural engineers familiar with the use of farm equipment, etc., before reliable classifications of land suitability can be made. There is a strong reliance on the experience obtained in other areas under analogous conditions.

It is fashionable nowadays to expect spectacular results from interdisciplinary cooperation. Indeed much of the thinking put forward in this report was obtained after looking into the kitchen of other disciplines, especially regarding methods of work, concepts and procedures in theoretical plant production, water management, agricultural economics and agricultural geography. However, it has also been rightly observed (Lekanne dit Deprez, 1976) that interdisciplinary cooperation introduces new problems of communication and organization. Soil scientists should remain soil scientists and agronomists be always agronomists. I hope that the systems approach proposed in Chapter 5 will be useful in managing this problem. The system analysis specifies, organizes and processes the contributions made by the various disciplines. A basic assumption of a systems approach is that each discipline should be given as much independence as possible to produce its own data. In many countries, land evaluation is the task of specialized natural resources institutions, which in the past may have concentrated in the first place on soil or vegetation survey, often the most variable attributes of the land. Such institutions have concentrated mainly on general purpose land evaluation. Future changes should be concerned especially with:

- more emphasis on climate
- more emphasis on biological and technical aspects of land use
- more attention to socio-economic aspects of land use
- more emphasis on fundamental land use - land relationships.

Burrough (1976) presents the following suggestions for future research in land survey and evaluation in Australia:

- to put less emphasis on research for its own sake and more on incorporating the results of research into the decision-making process. This implies the setting of specific research goals.

- to develop techniques of system modelling and analysis to aid resource appraisal

- to increase knowledge on the social and cultural perceptions of land and the ability of land to support socially and economically, as well a physically feasible land use options.

If such changes seem over-ambitious, one is reminded that the workload involved in the interpretative stages of land evaluation is minor when compared with the inventory stages, both in man days and operational costs.

c) An obvious drawback of the more pragmatic specific purpose land evaluation is the shorter duration of the validity of its results. The time variability of the technological and socio-economic factors introduced needs to be taken into account. The systems approach introduced in Chapter 5 should overcome this disadvantage by permitting easy feedback to fundamental data and revision of the interpretations when assumptions change. Particularly in societies with rapid technological and socio-economic change, the institutions involved in land evaluation are responsible for presenting timely revisions of their results before they become obsolete.

d) Separate land suitability classifications for different uses do not permit the performance of one use to be compared with the performance to be expected from another use, unless these performances are expressed in common (mostly monetary) terms. Comparison between different land utilization types for which the land is classified as suitable requires not only a physical analysis but also mostly a socio-economic analysis.

In the next section more attention will be given to this aspect of land evaluation. It may prove difficult for scientists in the physical disciplines to introduce into their working methods an element that increases their dependence on the cooperation of the socio-economic disciplines. Therefore it is best to maintain a clear distinction between the physical analysis in land evaluation or physical land evaluation, and the socio-economic analysis. In this report, the approach to land evaluation that includes both the physical and the socio-economic analyses has been named integral land evaluation.

4.2.1 Physical land evaluation

Physical land evaluation is concerned with predicting the performance of specific land use systems, as conditioned by the constraining influence of physical land conditions. Performance is expressed in physical terms.[1] The physical land conditions are the only variables that affect the rating of the performance of the land use systems, i.e. the physical land suitability classification.

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[1] *The term 'physical' as used in this report is set against "socio-economic".*

Physical land suitability classification with and without major land improvements

Often, land evaluation includes the consideration of major one-time improvements of the physical land conditions: irrigation, drainage, deep ploughing. Such improvements demand large capital investments. Careful physical and socio-economic analysis of the feasibility of these land improvements is needed to predict their effects on development and environmental conservation.

For an objective evaluation of major capital investments, a comparison is normally made between what would happen in the project area with and without implementation of the envisaged land improvements. Thus there are two land suitability classifications: land suitability classification for improved conditions (LSCi) and land suitability classification for unimproved conditions (LSCu).

As an intermediate step in predicting the effect of land improvements on the performance of land use, land evaluation includes a prediction of the effect that major land improvements will have on the constraining land qualities. For this purpose a distinction can be made between unimproved land qualities (LQu) and improved land qualities (LQi). The physical improvements are specified as precisely as possible in technical terms (e.g. subsurface drainage is expressed in terms of spacing and depth of tiles, materials to be used). Predicting the effect of land improvements can be difficult, requiring substantial local research and/or analogy. Care is taken that the technical specifications of improvement can be easily translated into costs during subsequent socio-economic analysis.

The distinction made in the *Framework for Land Evaluation* between current and potential land suitability is not quite satisfactory. 'Potential' is a vague term, which can easily be confused with 'maximum'. Especially in developing countries, land suitability after improvement, will represent performance levels that are far below maximum level.

Land use and land improvement decisions are a result of optimization that takes into account the most limiting factors: seasonal labour shortage, land tenure, availability of irrigation water, capital, etc. In view of the many limiting factors there will almost invariably be a substantial difference between the feasible level of performance and the hypothetical maximum performance that would be obtained if land use were limited only by the physical characteristics of a particular kind of land. Especially in areas with an established land use pattern, potential land suitability will be strongly influenced by limiting socio-economic-oriented factors inherited from the past. Specific purpose land evaluation takes this legacy into account.

Land suitability criteria

The land suitability class expresses the degree of fitness of a given type of land for a specified land utilization type. Distinction between different classes of suitability depends on the land suitability criteria that control the limits between suitable and unsuitable - between highly suitable and moderately suitable land. Land suitability criteria depend again on the criteria for optimal land use. The most common criteria are maximum benefit and minimum losses: land suitability classes express different levels of expected benefit and loss. This logic applies not only to the land suitability classification, but also to the land improvement specifications: optimum land improvements are those that produce the 'best' results, i.e. are most in agreement with the criteria for optimal land use.

Optimal land use performance is a socio-economic criterion employed (after translation into physical terms) in physical land evaluation for grouping lands in different land suitability classes according to the levels of expected performance. But physical land evaluation normally does not include commensuration in case the performance or land use 'effects' are expressed in different physical terms: expected yield, expected erosion losses, expected physical input requirements. A precise quantitative expression of each land suitability class to indicate the expected performance of a land utilization type on a particular land unit is beyond its scope. However, at the beginning of physical land evaluation, when the land utilization types are identified, explicit attention should be given to the selection of land suitability criteria for land evaluation for defining land suitability. A rating scale in terms of values taken by the criterion variables of e.g. yield levels, should permit a classification or ranking of the land units according to their fitness for a specified land utilization type.

Examples of land suitability criterion variables are:

- Yield level
- Performance reliability
- Multi-annual yield trend
- Flexibility for timing of field operations
- Flexibility in choice of equipment for field operations
- Levels of soil erosion losses per hectare
- Levels of physical inputs required
- Time period required for a major land improvement to take effect (e.g. desalinization)
- Time period that continuous cropping is possible (shifting cultivation).

In a physical land evaluation, the land suitability classes stand for different values of each criterion variable corresponding with the different degrees to which the land use objectives are expected to be met. In the absence of a common denominator for criterion variables of different dimensions, the land suitability classes are mostly verbal descriptions of the degrees in which the land use objectives are met. Expected outputs and inputs may be expressed in terms of dissimilarities from normal outputs and inputs with their standard deviations observed in the project area.

The following example of physical land suitability classification for traditional agriculture (no fertilizer, no mechanization) is from Brazil (see also Section 4.3.4):

Land suitability class I - good

Actual agricultural soil conditions[1] suited to a wide range of annual crops and tree crops. Relatively good yields (considering the management practices concerned) normally for a period of at least 30-40 years (tentatively), during which the productivity only decreases gradually.

Even under the assumption that productivity may decrease gradually, good land for this land utilization type is very scarce in Brazil, because fertility mostly decreases rapidly while the soil is used for agriculture.

Land suitability class II - fair

a) Actual agricultural soil conditions suited to a wide range of annual crops, after burning, with yields that are good during the first few years of occupation, but which will rapidly decrease to reasonable yields, considering the management practices, the latter normally lasting for a period of 7 until 30 years (tentatively) after the beginning of the occupation.

b) Agricultural soil conditions suited only for a restricted number of crops and tree crops, with relatively good yields for a period of at least 30 years (tentatively) during which the productivity will be nearly sustained.

c) Presence of permanent slight risk of crop damage, reducing yields; likely to occur once in a period of more than five years.

1 *'Agricultural soil conditions' in Brazil are the equivalent of 'land qualities'.*

Land suitability class III - restricted

a) Actual agricultural soil conditions suited to a wide range of crops, after burning, but only during the first years of occupation, since yields rapidly decrease to low yields within a period of 7 years (tentatively).

b) Actual soil conditions suited to a restricted number of tree crops, with relatively good yields, for a period of not more than 30 years, or reasonable yields during a longer period, with practically sustained production.

c) (In case of management system III) Actual soil conditions restrict considerably the use of animal traction and accompanying implements, or where (in case of management systems IV and VI) hand labour is difficult.

d) Presence of a permanent moderate risk of crop damage reducing yields, which is likely to occur once during a period of 1-5 years.

Land suitability class IV - not suitable

a) Actual agricultural soil conditions not suited for the cultivation of crops or tree-crops, since yields are already low in the first year of occupation, or when yields are not feasible.

b) Actual agricultural soil conditions make the use of animal draftpower impossible (system III) or impede practices based on manpower (systems IV and VI).

c) Actual agricultural soil conditions include a permanent strong risk of crop damage reducing yields, which is likely to occur once or more every year.

Class IVa - soils, suitable for extensive grazing

Class IVb - soils, not suitable for grazing

Source: Beek, Bennema and Camargo, 1964

From the example it will be understood that the definitions of land suitability classes are closely linked to the definition of the land utilization type. When no fertilizers can be added, the time period that the land can be utilized before it returns to fallow is an important criterion. In the example, flexibility in the use of tractor-drawn farm equipment is not a relevant criterion variable for the suitability classification as it does not affect the operations of this non-mechanical land utilization type. The identification of relevant land utilization types explores references that can also provide the criteria for distinguishing land suitability classes. When major land improvements are contemplated, criteria for the selection of optimal land improvements are needed e.g. of relevant drainage techniques in view of available government funds, and of prices and market prospects of envisaged crops.

Physical land evaluation for specific purposes thus requires some kind of preliminary, mainly qualitative, socio-economic analysis serving two purposes:

- to synthesize the most relevant land utilization types, as described in Chapter 2 of this report,
- to identify criterion variables and their significant values for the selection and specification of land improvements and to define the land suitability classes in terms of values taken by these variables

Qualitative versus quantitative land suitability classification

The degree of quantification in which the suitability criteria are expressed will depend on the purpose and detail of the land evaluation. Some criteria (such as yield) will be more easily expressed in quantitative terms than others (e.g. performance reliability or soil erosion losses). The more comprehensive the land evaluation (taking into account more effects resulting from the interactions between land utilization and its environment) the more difficult it will be to present purely quantitative results.

The FAO *Framework for Land Evaluation* makes a distinction between a qualitative land suitability classification and a quantitative land suitability classification (FAO, 1976, p.22):

> A qualitative classification is one in which relative suitability is expressed in qualitative terms only, without precise calculations of costs and returns.
>
> A quantitative classification is one in which the distinctions between classes are defined in common numerical terms, which permits objective comparison between classes relating to different kinds of land use.

It is questionable if land evaluation is well served by a distinction between qualitative and quantitative. The FAO document (p.22) admits that

> qualitative evaluations allow the intuitive integration of many aspects of benefits, social and environmental as well as economic. This facility is to some extent lost in quantitative evaluations.

It seems that even in the most detailed integral land evaluation, in which systematic socio-economic analysis is included, there will, most probably, be a multi-dimensional output consisting of physical, biological, social, economic and environmental effects, outputs and inputs which cannot easily be brought under a common quantitative denominator. On the other hand, physical land evaluation may be able to express some of its ratings in precise quantitative terms (e.g. yields, fertilizer inputs), whereas other land classification criteria remain qualitative: no - low - medium erosion losses expected. Thus the distinction between qualitative and quantitative land evaluation is blurred. In this report the distinction between qualitative and quantitative land suitability classification has been deliberately omitted. Land evaluation should always be as quantitative as possible, without compromising on its responsibility for predicting all physical, socio-economic and environmental effects of proposed land use changes or of a continuation of existing land use systems (see also the economic evaluation of environmental pollution: Opschoor, 1974; Hueting, 1975; OECD, 1974; Bouma, 1972; Pearce & Rose, 1975).

When are the land utilization types defined in physical land evaluation?

Two separate situations can be distinguished:

a) The land utilization types are synthesized at the beginning and are not modified during the later steps of the physical land evaluation procedure.

b) The land utilization types are broadly defined at the beginning and are modified and adjusted in accordance with the findings of the physical analysis. This is the case in more detailed land evaluation, especially when major land improvements are considered. Such refinements, which may also affect the selected criteria for land suitability and land improvement, represent a corrective feedback to the earlier described land utilization types. It is not an optimization of the land utilization types in the sense that they are ranked according to their performances if combined with a particular land unit. The latter is a task for socio-economic analysis in integral land evaluation. In physical land evaluation the land utilization types represent separate land use possibilities. Separate land suitability classifications are made for each land utilization type and sometimes for combinations of land utilization types (compound/multiple land utilization types).

In small-scale physical land evaluation, the suitability of each land unit will probably be classified for each land utilization type. In more detailed evaluations the suitability of a land unit will only be classified for the most pertinent land utilization types.

4.2.2 Integral land evaluation

Integral land evaluation is a combination of physical land evaluation and socio-economic analysis. Since physical land evaluation has been the subject of the previous paragraphs, I will now discuss mainly socio-economic analysis in land evaluation.

Socio-economic analysis in land evaluation has two main tasks:

a) commensuration of the multi-dimensional land suitability classification produced by the physical land evaluation: land suitability classification in common economic terms.

b) to find the optimal land use for different classes of land: optimization of land use.

a) Land suitability classification in economic terms

This is a synthesis of the physical land suitability classification and the relevant socio-economic factors. Appropriate product and input prices that define the physical land suitability classes are applied to the physical inputs and returns. Sometimes socio-economic analysis of the land utilization types, following the methods described above, produces new information that needs to be fed back into the physical land evaluation so that its findings can be revised. Ideally, the analysis of land use performance in the light of physical land variables, and the land suitability classification in economic terms should proceed simultaneously, one supporting the other. This will mostly be the case in detailed land evaluation, but in less detailed studies, physical land evaluation and socio-economic analysis can be separate studies. At the reconnaissance level in particular, there can be a considerable time lapse between the physical land suitability classification and the land suitability classification in economic terms. An example is the natural resources survey executed with OAS assistance in Chile, discussed in Section 4.3.5.

Generally, in reconnaissance land evaluation, socio-economic analysis is limited to selecting the most promising land utilization types. On the basis of a physical land suitability classification, those lands that are of interest for more detailed land evaluation are selected. Only during these subsequent studies will the necessary data be collected to translate the land suitability classification into economic terms of net benefits, repayment capacities etc.

At the *semi-detailed level* the economist will usually carry out cost benefit analysis or gross-margin analysis on a tentative basis so as to offer early guidance on how the land utilization types being considered will perform in connection with different classes of land. This exercise also helps to raise the general level of analysis and reporting, by forcing the land evaluator to make the necessary assumptions, including the key attributes of land utilization types and the expected physical outputs and inputs, for suitability rating. During the semi-detailed land suitability classification in economic terms, feedback to the physical land evaluation is common practice. For purposes of land use planning, land classes will often be established at semi-detailed level, first in physical terms, and after that, subject to possible modifications, in economic terms. These classes provide the background for detailed land use planning.

At the *detailed level*, socio-economic analysis is more concerned with optimizing the land use than with the commensuration of physical land suitability classes in common economic terms. Often, non-physical factors will receive more attention than physical land variables in the land use optimization process.

Land suitability classes in economic terms do not necessarily coincide fully with the physical land suitability classes. The latter classes, however, do support the determination of suitability classes in economic terms by providing essential data on technical input coefficients as well as on returns to be expected (in the first place yields, but also other secondary and intangible benefits and services).

b) Optimization of land use

This process is initiated at the beginning of the physical land evaluation with the synthesis of the most promising land utilization types, as described in Section 2.4.

During integral land evaluation, the optimal type has to be selected and sometimes combinations need to be made to arrive at optimal systems of rotation or multiple use. In multi-annual land reclamation projects, the ultimate goal of land evaluation will sometimes be the production of a sequence of land utilization types, replacing each other in accordance with the progress made with land improvement e.g. desalinization. Optimization of land use shows an increase in quantification and reliance on socio-economic data with increasing detail of land evaluation (Robertson, Luning and Beek, in FAO, 1975b).

At *reconnaissance* level socio-economic analysis is unlikely to go further than a synthesis of relevant land utilization types at the beginning of (physical) land evaluation. A general socio-economic framework is established[1] and a qualitative inventory is made of development constraints and possibilities. Constraining qualities of the socio-economic environment identified at this stage might include adverse land tenure conditions, inadequate legislative aspects of soil and water conservation, seasonal labour shortages or unemployment, poor access to markets and services, market prospects of main crops of the project area and comparative advantages in relation to other areas producing these crops, price policies, etc. Conclusions are unlikely to be expressed in quantitative terms unless the amount and quality of existing data justify a quantitative analysis. Much of the information is likely to derive from discussions with farmers, traders and officials and from publications by government and other development agencies (World Bank, FAO). Sometimes farm surveys will be important for the analysis of present land use and broad development perspectives. Examples of such studies at reconnaissance level are the INCRA (1973) survey and evaluation of natural, socio-economic and institutional resources of Rio Grande do Sul, Brazil, and the SUPLAN studies of potential land use (Beek, 1975d). Also the Kenya Soil Survey uses an agro-

1 *e.g. through agricultural sector analysis*

economist for the systematic identification of land utilization types (Luning, 1973; de Jong, 1977):he carries out a preliminary farm survey to collect the pertinent real data.

At the *semi-detailed* level or intermediate level, the form taken by socio-economic analysis depends greatly on the quality and quantity of existing data. Where data are scanty, the analysis will incline towards the approach followed to synthesize relevant land utilization types in the reconnaissance phase. Where data are more plentiful, the analysis will more probably approximate the methodology appropriate for the detailed phase. Where necessary, a global farm survey confined to the structure of the farm enterprise will be carried out. Linkages between land utilization types and farm types will need to be established. Stratified random sampling based on ecologically and agriculturally homogeneous zones will allow extrapolation to the required area level. Sometimes a detailed farm survey with emphasis on the production process will be useful. In this micro-analysis, attention should not be confined merely to production-oriented objectives but should also comprise other national development objectives, e.g. self-sufficiency in food, employment, income distribution. The major focus could be on particular target groups, such as - on the one hand - the farmers who are in a stage of transformation, cultivating new crops, using new techniques and other inputs; on the other hand, small-scale traditional farmers, consisting of the poorest with the lowest risk-taking capacities, who have remained out of reach of rural services and technical assistance.

The *detailed* level of land evaluation is the most appropriate level for optimizing land use. Reconnaissance and semi-detailed levels should produce no more than preliminary approximations of recommended land uses. Now, farm level optimization techniques may be used beneficially to give guidance in realistic farm planning. Techniques such as budgeting, programme planning and mathematical (linear) programming, known already from detailed land use planning, will be selected.

Socio-economic analysis is based on data produced by the detailed farm survey, the availability of resources and their allocation by producers: water, agro-chemicals, labour, capital, land of a certain suitability etc., input-output relationships, sales patterns and prices and costs. Also taken into account are credit needs and availability, tenure arrangements and market systems, the nature of social groupings and the interactions among them, and the values and attitudes of prospective producers.

Criteria for socio-economic analysis in integral land evaluation

Robertson, Luning and Beek (in FAO, 1975b) have singled out the following criteria:

- Net benefit and repayment capacity of loans for land improvement are the best known criteria for distinction between land suitability classes in economic terms. An example is the United States Bureau of Reclamation Classification for Irrigated Land Use. The proposed types of land utilization, sometimes combined into more complex farming systems, should be commercially attractive when operating on the land under consideration from the point of view of the land user (the farmer or the company).When big investment loans are involved, the repayment capacity of the beneficiaries also needs to be reviewed (Price Gittinger, 1972).

- Simultaneously, a social cost-benefit analysis should discover whether the proposed development will benefit society as a whole. This requires adjusting costs and prices where relevant in order to correct foreign exchange deviations and other distortions (taxes, subsidies). This analysis is concerned with the true scarcity value of resources to the society.

- Apart from calculating the returns to scarce capital and other resources, as carried out in the conventional cost-benefit analysis, due attention needs to be paid to the possible trade-offs with other objectives (employment, income distribution, efficient use of fossil energy, minimization of environmental pollution). Appropriate weight should be given to these other objectives. Sensitivity analysis could be usefully applied.

Staged and parallel land evaluation procedure

Integral land evaluation may follow two rather different procedures (Beek, in FAO 1975 a):

In a staged procedure the stage concerned with physical land evaluation is followed by a stage concerned with socio-economic analysis as described in the previous paragraphs.

In a parallel procedure socio-economic analysis proceeds concurrently with the physical land evaluation at a comparable level of detail.

Up until now the staged procedure was referred to as 'two-stage' procedure: this term has been adopted for the *Framework for Land Evaluation* (FAO, 1976). But strictly speaking the staged procedure consists of three stages:

1. preliminary socio-economic analysis for the synthesis of land utilization types, land suitability criteria and land improvement criteria to be used during the physical land evaluation. It has been said earlier that this kind of socio-economic analysis is not necessarily a task of land evaluation; the information about land utilization and criteria may also be contained in the terms of reference for the land evaluation study (pre-established land utilization types, most common in general purpose land evaluation).

2. The physical analysis.

3. The complementary socio-economic analysis: land suitability classification in common economic terms and the optimization of land use for specific land conditions.

There can be a considerable time lapse between stages 2 and 3. Sometimes there will be no stage 3 but a more detailed follow-up land evaluation study of some areas selected from the data produced during stages 1 and 2.

4.2.3 Choice of land evaluation methods

Exploratory and reconnaissance type studies rely mainly on physical land evaluation. Such evaluations concentrate on identifying physical constraints and possibilities at regional and national levels, and are mainly carried out by institutions that specialize in physical resources studies. The rather generalized land suitability classifications that are produced should be valid for a long time. When the study area is large, climate is an important variable both in terms of spatial variability and because of seasonal and multi-annual variance. Results provide the physical geographical base for medium- and long-term plans, and the selection of priority areas for more specific studies, and more detailed land evaluation. Examples of problem-oriented studies that can be identified during a reconnaissance physical land evaluation are: the installation of rain gauges, piezometers and experimental fields for artificial drainage, use of chemical fertilizer, pilot areas for soil conservation and water management. A special application of physical land evaluation is the prediction of biological production potential, as conditioned by site-specific physical factors. Although in such rather theoretical studies the emphasis is usually on the climatic factors, other physical variants such as soil, natural vegetation and topography can be introduced as reduction factors for the climatologically feasible production potential (Buringh *et al.*, 1975, 1977; Nix 1968; FAO Agro-Ecological Zones Project, Africa Report 1978).

Today's interest in long-term planning and environmental control at regional and global level, shown by the Club of Rome and the U.N. System (Garbutt *et al.*, 1976; Linneman, M., 1977) is adding a new stimulus to the national interests in small-scale physical land evaluation.The challenge is to introduce into such studies specific target groups (e.g.low income versus high income farmers, *minifundios* versus *latifundios)* for a better analysis of development alternatives in the light of physical constraint and structural development problems. Specific purpose land evaluation should be able to contribute, also at small scale, as will be demonstrated in Section 4.3 for Latin America.

At larger scales (usually greater than 1 : 50 000) physical land evaluation serves more specific purposes connected with project planning, design and implementation: feasibility studies for land reclamation and improvement, settlement, reallotment, farm planning, soil conservation, rural extension.

The borderline between physical land evaluation and integral land evaluation becomes less clear. At the semi-detailed level, the physical land evaluation is carried out mostly as part of a staged integral land evaluation procedure. Physical development problems and improvement possibilities are examined and the results expressed in such a way that commensuration into economic terms can be easily done. The accent will be in the first place on subdividing the project area into land classes with different physical possibilities for alternative uses (conceptual physical planning). The predictable yields, the broad techniques and costs of land improvement, and the possibilities for carrying out the main farm operations are important. Semi-detailed land evaluation frequently serves as an introductory stage for detailed land evaluation. At this scale we are concerned with the formulation of specific projects and their implementation. The range of land conditions will already be known from previous less detailed studies, and also their suitabilities for specific land utilization types, both in physical and economic terms. At a detailed level, the geographical base (land resources map) needs to be refined (1 : 5 000 - 1 : 10 000 scale mostly).

A few properties of the soils are added or are described more precisely, thereby increasing the accuracy of the predictions of performance. These predictions will be limited to the most promising land use alternatives. Such refinements will be influenced mainly by the variable topography and hydrology and also by the existing physical infrastructure. Because of its limited size, a project area usually belongs to a homogeneous climatological zone. Therefore the interpretation of climatic data concentrates exclusively on detailed analysis of the time-variable influence of climate on the performance of the land use during its various stages of development: land clearing, land preparation, sowing, germination, vegetation growth, ripening and harvesting - this for a sequence of years.

Because of the greater influence of socio-economic variables, and the possibility of limiting the analysis only to the most relevant land use alternatives, detailed land evaluation is likely to opt for an integral land evaluation with parallel procedure.

4.2.4 Land evaluation and land use planning

There is no sharp distinction between land evaluation and land use planning. Whoever is involved in land suitability classification is himself involved in land use planning. Choices are made regarding the application of scarce physical inputs and their effect on the productivity of the land is evaluated. Land use planning is concerned primarily with the economic aspects of land use and land use changes. But a physical land suitability classification that expresses its outputs in kg yield per ha and the corresponding inputs in kg/ha or labour hours per ha already uses economic, if not common monetary terms. If, for some practical reason, any sharp boundary is to be maintained between technical and other disciplines in land evaluation, it should be between the inventory stage proper and the subsequent interpretive stages.

Fundamental distinctions between physical land evaluation, socio-economic analysis and land use planning have evolved from the fundamentally different approaches of different institutions: these need to be coordinated. Already the development of a multi-disciplinary approach to land evaluation has stimulated the introduction of new concepts serving this purpose. One of them is the concept of land utilization types, which lies on the borderline between environmental sciences, farm economics and planning.

Its function is not limited to the scope of a purely physical land evaluation for specific purposes, but has also been demonstrated for integral land evaluation. Here the land utilization type concept merges with already established concepts and theories in farm management (farming systems, cost-benefit analysis, production functions) and in land use planning (regional plans, farm plans, production plans. To illustrate its role, and to summarize the discussion on land evaluation methods of this chapter, a flow chart has been prepared.

This scheme shows the procedures of land evaluation at three levels of detail. For reasons of simplification, it has been assumed that:

- at reconnaissance level a physical land evaluation is carried out followed by a very generalized socio-economic analysis
- at semi-detailed level an integral staged procedure is followed
- at the detailed level, preference is given to an integral parallel land evaluation procedure.

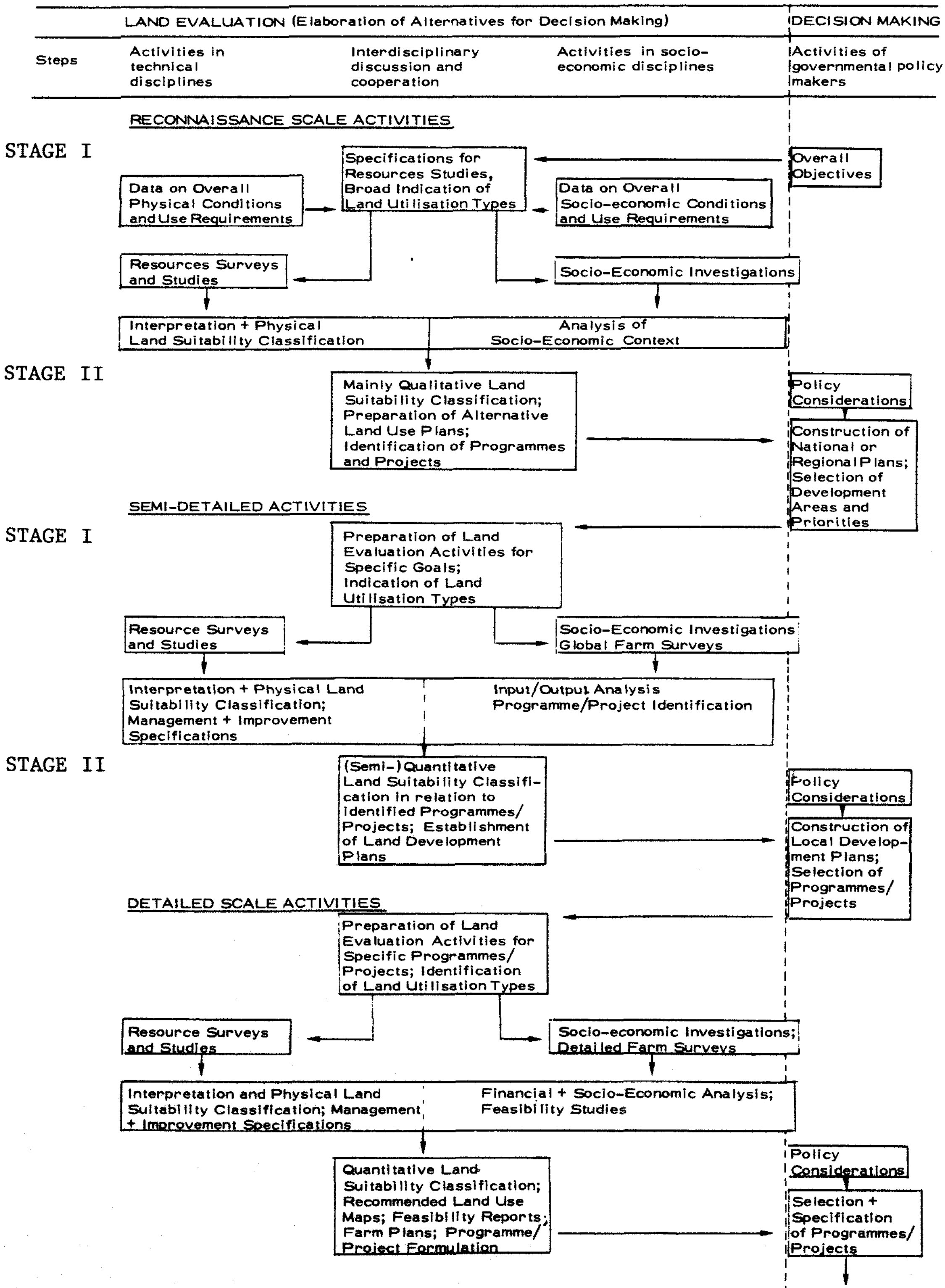
Of course, many other combinations could be brought to mind. Beek (in FAO, 1975b, see also FAO, 1976) earlier presented two separate schemes for integral land evaluation methods; one that follows a staged procedure at the three mentioned levels of detail, and another that shows the parallel procedure at the three above-mentioned levels of detail.

Land use planning activities

The *Framework for Land Evaluation* (FAO, 1976) indicates the role of land evaluation in land use planning, presenting the land use planning process by the following generalized sequence of activities and decisions:

a) recognition of a need for change
b) identification of aims
c) formulation of proposals, involving alternative forms of land use, and recognition of their main requirements

GRAPH 4.1: FLOW CHART OF LAND EVALUATION PROCEDURES



d) recognition and delineation of the different types of land present in the area

e) comparison and evaluation of each type of land for the different uses

f) selection of a preferred use for each type of land

g) project design, or other detailed analysis of a selected set of alternatives for distinct parts of the area.
This, in certain areas, may take the form of a feasibility study.

h) decision to implement

i) implementation

j) monitoring of the operation

A major role for land evaluation is reserved regarding the stages (c), (d) and (e) in the *Framework*, which is mainly concerned with physical land evaluation. Stages (a) and (b) are identified by the decision-makers. Of course, broad reconnaissance-type land evaluations can bring important elements to the attention of the decision-makers. For instance, in Brazil it was shown with reconnaissance-level information that the increase in cultivated area projected by the government for the southern and south-eastern region would meet with great difficulty and that more attention needed to be given to an increase of productivity per hectare, requiring, amongst other things, more detailed land evaluation for purposes of crop zoning and soil conservation. The same study also brought deficiencies in the farm structure (the concentration of unused, cultivable land in *latifundios)* to the government's attention, showing them to be a constraint on the free expansion of the cultivated area in southern Brazil (Pereira *et al.*, 1975).

At the more detailed level, integral land evaluation is also involved in stages (f) (which corresponds to the optimization of land use for a given class of land) and (g) (which is concerned with the planning and design of land and water use changes). Planning and design will, as long as possible, attempt to elaborate alternatives for the decision-makers to consider during stage (g). Even during stage (h) (implementation), there can be considerable feedback to the land evaluation if new problems arise or assumptions change during implementations that require a considerable time span, such as land reclamation, polder development, desalinization, flood control. Sometimes it is more practical to limit the land evaluation to a few alternatives, start implementation as soon as possible and make the revision of the land evaluation a matter of principle. This applies not only to major land reclamation and improvement projects, but also to land evaluation for current conditions. Beek (FAO, 1975a) sees land evaluation as a continuous process that should be executed as a permanent supporting service to farmers, planners and other users of land resource data.

Land evaluation is more than an *ad hoc* activity in a sequence of steps which precedes the implementation of a specific development project or plan. Planners, researchers, farmer-supporting services (extension, credit) and last but not least the farmers themselves should have continuous access to and be assisted in the analysis of land resource data. Pragmatic land evaluation should be able to contribute to the formulation of concrete management recommendations and their constant revision in the light of the continuously changing values of other production factors,inputs and outputs to assure optimal land use.

4.2.5 Land evaluation and the individual farmer

The farmer's role: (a) Closer cooperation between land evaluation and local farmer

Existing land evaluation procedures emphasize the importance of well-defined land use and land improvement recommendations. This may have created the wrong impression of a rather academic specialist's job, resulting in the preparation of 'cookery book recipes' on how to use each tract of land. It would be a misunderstanding if the role of the individual farmer were to begin where the land evaluation procedure stops.

In virtually every aspect of the land evaluation fieldwork, the user of the land needs to be consulted, his operations observed, his achievements, attitudes and expectations taken into account. The proposed land evaluation methods and related concepts require this, particularly for a proper matching of land qualities and land improvements with land utilization types. Proper observation, analysis and rating of the factors involved will require close contact with the farmers. For instance, to be applied properly, the concept of land quality needs more information on the behaviour of the natural vegetation and of cultivated crops, than the description of land properties according to pre-established manuals or guidelines and the interpretation of such individual properties. The land quality concept puts the field surveyor in a better position to translate his widely acknowledged 'feel of the land' into more digestible and readily applicable formulas than before. On the other hand, this will place higher demands on his agronomic and biological insight, and this is where local farmers will be of great help. The same applies to the identification of land requirements of utilization types, and the selection of land management and land improvement recommendations. Land use recommendations that reflect some of the 'grass roots' experience of local farmers are likely to be more easily accepted by the land users.

The farmer's role: (b) his decisions

Even the most precisely defined land use recommendations cannot take full account of the variables involved in the proper utilization of a tract of land. Land management specifications contain information that complements the definitions of the land utilization types. To be applied, these data will require further interpretation, adaptation and elaboration by the actual land user to suit his situation. This situation may vary according to location, year, season, weather conditions, economic conditions (market conditions, price signals, labour market), life stage of the farmer and his family, to name but a few variables that land evaluation can never take into account fully. Land use recommendations should be relevant for most of the range of conditions that may occur, but should not become excessively detailed by attempting to give a specific solution for every situation in this range. Extreme situations may not be covered at all by the land evaluation procedure. Sometimes, extreme situations are unjustly cited to prove that the entire land evaluation procedure is inadequate. For instance, the sudden increase in fertilizer prices that occurred during 1973/74 may have given rise to strong doubts about the usefulness of land evaluations proposed for specific purposes. Indeed, such extreme situations do occur, but fortunately not every day; it is to be hoped that serious efforts are also made in other fields such as agricultural planning, to increase the reliability of the agricultural enterprise.

In this context, Singh's observation (1974) holds true:

> *local decisions with regard to activities to be taken up in a given area, and determination of priority amongst different proposed activities should be left to beneficiary farmers themselves and should not be taken by anybody from outside howsoever important he may be. Outsiders and experts should therefore only outline different alternatives, the final decision being the prerogative of the beneficiaries alone.*

4.3 Land evaluation in Latin America

To illustrate the land evaluation concepts and procedures that have been explained in previous chapters, land evaluation methods from five Latin American countries will be described.

The examples from Venezuela, Nicaragua and Mexico have in common that they represent attempts to adapt the general purpose USDA-SCS Land Capability System to local needs and circumstances. The Brazilian method is a new land evaluation system based on land qualities and land utilization types. The first four examples are all concerned with physical land evaluation. The fifth, from Chile, has been included to describe an interesting and simple method for stage II, the socio-economic analysis, of an integral land evaluation method with staged procedure.

The examples from Brazil and Nicaragua have actually been applied in the field. Those from Venezuela, Mexico and Chile represent theoretical proposals in the present search for new land evaluation methods.

The Venezuelan method remains closest to the USDA Land Capability System: no effort has been made to make land evaluation use-specific. Only two very broad land utilization types have been considered: one that uses all kinds of agricultural inputs except irrigation and drainage and one that includes irrigation and drainage. A significant step forward in the Venezuelan method is the way in which the combined influences of climate and soil on land capability have been specified.

Twenty-two bio-climatic life zones have been distinguished, and for each such zone a semi-quantitative conversion table that relates land features with land capability has been prepared. Because of the climatic differences between life zones, the value of a particular soil characteristic (e.g. soil depth) sometimes receives a different weight in the land capability classification of different life zones.

The modifications succeed in overcoming the criticism made against the

USDA Land Capability System for not being sufficiently specific in its correlation between land features and land capability classes. However, to arrive at a specific purpose land evaluation, the land utilization types will need to be defined in more detail, thus enabling the identification of their land use abilities and land requirements. A refinement of the correlation between land characteristics and land capability classes is lost to a certain extent when this correlation does not reflect the degree to which the land characteristics meet the specific requirements of the utilization types.

The Nicaraguan land evaluation was carried out for purposes of natural resources inventory and land taxation. The amount of information presented goes far beyond what is normally contained in soil survey reports in Latin America. Both a general purpose and a specific purpose land evaluation have been included. Unfortunately the two evaluations became rather mixed up.

Various valuable items of information about land capability, land suitability, soil management and conservation specifications (inputs), and yield potential (outputs) have been presented without making sufficiently clear the relations that exist between them.

The more than 600 soil series and types distinguished during the soil survey were first grouped into USDA-type land capability classes, sub-classes and units. The result was a drastic simplification of the data base into only 66 land capability units. These units, the product of general purpose land evaluation, were then interpreted according to their suitability (four class system) for 25 irrigated and rain-fed crops, for pastures, and for five types of woodland production (specific purpose land evaluation). Obviously, a land suitability classification of each of the 600 soil series and types in combination with the various produce types mentioned would have been a much more elaborate task. To arrive at more realistic management assumptions, these produce types should have been combined with other key attributes of land utilization such as technological level, capital level and available labour. This would have increased the number of interpretations (LUT, LU combinations) even more, although many of them would have been deemed irrelevant at the start of data interpretation. In the Nicaraguan example the land capability unit also stands model for the land conditions when the soil management and conservation practices (inputs) are specified. In these specifications a distinction has been made between two levels of management: 'average' and 'improved'. But an interpretation of (groups of) land capability units in terms of management and conservation practices for different management levels presents us with a contradiction: to group soil units into land capability classes, sub-classes and units, the assumed management level has to be established beforehand. If it were decided at a later stage to distinguish between different management levels, this would contradict the management assumptions underlying the land capability classification. The 'average' management level and the improved' management level are likely to give rise to two different groupings of soil series and types into land capability units. Management specifications have been given for one to five different groups of land capability units, depending on the type of crop. Conservation specifications have been presented for twenty groups of land capability units. This primary concern with conservation is probably the best feature of the USDA Land Capability System.

We learn from the Nicaraguan example that land evaluation results are strongly conditioned by the land utilization types chosen. A systematic procedure is needed to arrive at a clear presentation of input-output relations for pertinent combinations of land utilization types and (groups of) land mapping units. General purpose and specific purpose land evaluation will need to be separate studies when the management assumptions underlying them are not the same.

In Mexico CETENAL (the Commission for the Study of the National Territory) is making a natural resources inventory at the scale 1:50 000. Their land evaluation methodology adheres strictly to the USDA Land Capability System. New proposals by CETENAL for making land suitability maps in the future include a general purpose land evaluation and a specific purpose land evaluation.

In the general purpose land evaluation a distinction has been made between land capability for unimproved conditions, the 'agrological capacity' classification, and the land capability for improved conditions, the 'potential capacity' classification. Eight capability classes have been defined in a conversion table in terms of specified values of eleven selected land properties/qualities. Emphasis is placed on the land quality 'available water', which has been specified in terms of climatic classes (Köppen classification).

There is no mention of land utilization types or of management levels, apart from the statement that adequate techniques will be applied in realizing land improvements. Eight major improvements have been listed: irrigation, leaching, application of amendments for alkalinity control, stone removal, liming, flood control, drainage, and erosion control. The level of inputs required for land improvement can be deduced solely from these qualitative references to the types of major land improvement. The effectiveness of the input applications has to be read from the difference between the potential capacity class and the agrological capacity class. There is no mention of outputs (yields).

Essentially, the eight classes of agrological and potential capacity are no more than systematic groupings of land mapping units with similar levels of selected land properties/qualities. Although no capability class definitions have been presented, it seems that inputs and outputs are no criteria for the general purpose land evaluation method.

In the specific purpose land evaluation, the physical possibilities of growing more than one hundred different crops, forage, and forestry species are assessed. For this purpose the country has been divided into four major climatic zones: arid and semi-arid, sub-humid with dry season, sub-humid, humid all year round. Within each major zone, four temperature regimes are distinguished: hot, semi-hot, temperate, cold. Differences in water availability in each of the 16 resulting climatic zones have been rated by using the levels of available water defined for the general purpose land capability classes (based on the Köppen classification).Apparently two climatic classifications have been superimposed here.

The specific purpose land evaluation also includes a crop tolerance level for effective soil depth, salinity, alkalinity, and acidity. Since hundreds of different combinations of crops may result, a numerical key has been developed in which each combination is indicated by a different number. Separate ratings are presented for the unimproved and for the improved land conditions.

The proposed system is a two-class specific purpose physical land evaluation: Class I-suitable, Class II-unsuitable. Correlation between these two classes and the eight land capability classes of the general purpose land evaluation may exist, but the methodology has not been designed to be conclusive about such a correlation. Unlike the Nicaraguan example, the two land evaluation procedures are separate exercises. The Mexican method, however, is much less specific about such fundamental data for land use planning as yields, hazards, inputs. One also gets the impression that the methodology still lacks an adequate body of knowledge about the land requirements of the great many crops considered.

The emphasis placed on climatic variables is most valuable, although more attention will need to be given to the interactions between soil and climate.

Apart from the produce factor, other key attributes of the land utilization types should be explicitly mentioned in the future, considering the high percentage of farmers who can apply only small amounts of capital inputs.

In Brazil the Soil Survey and Conservation Service of EMBRAPA (Ministry of Agriculture) has developed its own system of land evaluation. The system permits each land utilization type to be classified into four suitability classes. The factors determining land suitability are the five land qualities: natural fertility, availability of water, availability of oxygen in the soil, resistance to erosion, absence of impediments to the use of mechanical implements. Each land quality has been defined at three to five levels of limitation (Appendix 2).

Inputs have an appropriate place in the system. The feasibility of improving the land qualities is rated as follows: improvement easily feasible, improvement feasible, improvement perhaps feasible, improvement not feasible. The land utilization type, called management system in Brazil, determines which land improvements are pertinent.

The ease and level of input needed for land improvement are important criteria for land suitability; another is yield. Sustained production and erosion control are necessary criteria for the land utilization types that require physical inputs for land improvement, although a decrease in productivity and some erosion losses are considered inevitable in the traditional low input type of land utilization. Because of these differences in suitability criteria, separate definitions of land suitability classes are presented for different land utilization types. Land utilization types are defined in terms of produce, farm power (manual, animal, tractor), capital intensity, and technological knowledge (low, medium, high).The key attribute 'produce' is normally divided into short cycle (annual) crops, long cycle (perennial) crops, planted pastures, natural pastures, silviculture. In a few cases individual crops have been considered: cocoa, sugar cane, *Pinus elliottii*.

Normally two or three interpretative maps accompany the soil survey reports to show the suitability for the relevant land utilization types. For regional planning purposes one single map, that combines all the interpretative information is now being presented: the multi-purpose land suitability map. The presentation is similar to that of the USDA Land Capability System with the distinction that the Brazilian methodology considers three levels of management for crops and two levels of management for grazing.

Conversion tables are the backbone of the land evaluation method. In these multiple entry tables land qualities and the feasibility of their improvement are related to the land suitability classes. For each land utilization type a separate conversion table is needed. The tables are both use-specific and site-specific because, except for the availability of water, no climatic variation is included in the land qualities that determine land suitability.

Conversion tables in Brazil do not consider the cumulative effect of different land qualities. The land suitability class is determined by the most limiting land quality after improvement. This problem still needs to be solved.

The reliability of the conversion tables depends greatly on the availability of site-specific research-tested information. Since such information is often hard to obtain in areas where reconnaissance land evaluations are needed, the transfer of knowledge through correlation and analogy with better known areas is important. In Brazil the use of land qualities has been of great aid in permitting this transfer of knowledge, while the attention Brazil has given to soil classification and soil correlation has been most valuable for systematic soil survey interpretation.

It must be admitted that there is now a great need in Brazil for conversion tables that permit land suitability classification for more specific types of produce: for individual crops, crop associations, and rotations grown at defined levels of management. More attention should also be given to climatic parameters and to soil conservation. This will require more participation from agronomists and agro-meteorologists. Only by incorporating these studies will the Brazilian methodology reach the full status of a specific purpose physical land evaluation. After achieving this, the methodology should be able to meet the data requirements for application of systems analysis and land use simulation in land evaluation and land use planning, as will be explained further in Chapter 5. The method as it stands now is intermediate between general purpose and specific purpose land evaluation, giving reasonably satisfactory results in reconnaissance land evaluation, but results that are too superficial at more detailed levels.

The example from Chile has been chosen to show how the results of a physical land evaluation were to be used ten years later for detailed land use planning in agrarian reform areas. The planning methodology is also a good example of Stage II in an integral land evaluation with staged procedure i.e. the socio-economic analysis. This method attempts to combine single land utilization types into compound land utilization types (crop rotations) with the objective of maximizing the use of labour and the labour income. It takes into account the physical limitations of the land, the availability of labour, the prices of inputs and outputs, and the market restrictions for certain products. In this process of land use planning there is a strong reliance on the results of Stage I: the physical land evaluation. Unfortunately a sharp discrepancy exists between the reliability of the data produced during Stage I and the data requirements of Stage II.

Stage I is represented by a large integrated land resources survey, based on the interpretation of aerial photographs covering an area of 120 000 km^2. The study distinguishes 350 soils, classified in terms of series, types, and phases. Field checks were made at an average observation density of 1 per 1100 ha with a range of 1 per 270 ha to 1 per 2700 ha. Data interpretation resulted in a map of land capability classes and sub-classes at the scale 1:20 000 (USDA Land Capability System). This publishing scale suggests a soil sampling more detailed than it actually was.

When examining the method of socio-economic analysis proposed for Stage II, one has to conclude that this method cannot rely entirely on the general information produced during Stage I. More detailed soil surveys of parts of the Central Valley by the Chilean Soil Institute confirmed these reservations. Physical land evaluation should be careful not exceed its claim as to the usefulness of its products. Clear statements about the reliability of maps and other data are needed.

A fundamental piece of information for Stage II should have been the productivity ratings for individual crops. But Stage I was not concerned with individual crops, only with very generalized types of land utilization: (annual) agricultural crops cultivated with modern management techniques (e.g.mechanized) and supplied with the necessary inputs for soil improvement and conservation. (Stage II is more concerned with other types of land utilization that permit maximum labour absorption.) To select optimal crop rotations during Stage II, crop yields were correlated with land capability classes, although for a proper assessment of productivity and yield potential reference should have been made to the soil units. Such misunderstandings between persons responsible for Stages I and II can be avoided if the presentation of the results of Stage I includes a productivity rating of crops for individual soil units or groups of similar soil units, preferably in combination with corresponding inputs required.

To sum up: Land evaluation in Latin America is relied on as a fundamental source of information for agricultural development. Land evaluation methods that evolved in other countries, especially the USDA Land Capability System, have not been rigidly followed. New systems are being developed to suit local needs. The observed willingness of national scientists to abandon established methods of land capability classification is encouraging the introduction of new approaches which pay more attention to land utilization and in particular to the land user. It must, however, be stated that a more integral study of the components that make up the land conditions, particularly climate and soil, is needed. In such more specific purpose oriented land evaluations, the dynamic aspects of land and land use can no longer be ignored. In view of the complexity of a land evaluation that considers the temporal problems of land use, data analysis will become more complex. With today's data-handling techniques, however, such problems of data analysis need not be insurmountable. In elaboration of this idea, some initial explorations towards the use of systems analysis in land evaluation are presented in Chapter 5.

Readers who are more interested in general methodology than in further details on the methods of land evaluation in the five Latin American countries may turn directly to Chapter 5.

Those who want to take a closer look at the Latin American methods will find further information, mainly in tabular form, in Sections 4.3.1 - 4.3.5.

4.3.1 Venezuela: adapting the USDA Land Capability System to local needs

The number of soil scientists in Venezuela has grown rapidly during the last decade, especially in the field of soil survey and classification. Their methods are strongly influenced by USA standards, laid down in the *Soil Survey Manual*, the Soil Taxonomy and in the Land Capability System. In 1968 a national land resources inventory started, ordered by COPLANARH (the Commission for the National Plan for the Utilization of Hydraulic Resources). The first phase of the project included the study of the country north of the Orinoco river. A rapid 1 : 500 000 reconnaissance survey was planned, based on the measurement of selected soil features that are rated and used independently of one another to designate soil (mapping) units. Avery (1968) termed this method a 'coordinate' system, a term used again by van Wambeke (1972) in his description of soil survey methods in Latin America. Coordinate systems should be distinguished from 'hierarchical' systems of classification (e.g. the U.S. Soil Taxonomy) which place more emphasis on the relationships between soils and the factors responsible for their features.

'Coordinate' systems have also been used in other parts of Latin America, for example in Chile (OAS, 1964; see also Section 4.3.5) and in Panama for rural cadastral purposes (CATAPLAN, 1964).

To interpret the first soil survey (Unare and Neveri) COPLANARH (1969) adopted a numerical system which raised many critical questions after publication. The original idea was to incorporate, as much as possible, the land suitability criteria laid down in the regulations of the national land reform law, chap. XV, articles 238-250. Unfortunately these criteria happened to produce a suitability classification bearing little relevance to real land use problems. The system assigned numerical values, scale 0-100, to soil properties: relief, effective soil depth, texture, degree of erosion, fertility, erodibility, drainage. For example, the rating of:

effective depth	numerical value
> 100 cm	61-100
50 - 100 cm	41-60
25 - 50 cm	21-40
< 25 cm	0-20

By attributing different weights to each soil property and after some mathematical manipulation a 'land use possibility' class was found, based on the following six-class numerical system:

Class I	90 - 100
Class II	80 - 89
Class III	70 - 79
Class IV	60 - 69
Class V	40 - 59
Class VI	< 40

Since little correspondence was found between the classes obtained and the real land use possibilities, it was decided to look for other methods. One of the alternative methods studied was the new Brazilian methodology for interpreting reconnaissance soil surveys (Bennema, Beek and Camargo, 1964). Finally it was proposed to adapt and refine the USDA Land Capability System (Klingebiel and Montgomery, 1961) for local needs. Several concepts and proposals from the Brazilian method were adopted.

The most significant proposals made in Venezuela will now be discussed (from: Comerma and Arias, 1971). They were presented during a Seminar on Soil Survey Interpretation for Agricultural Purposes, held in Maracay, 1971. Scrutinizing the USDA Land Capability System the following observations were made:

a) Class-designations should be less subjective. For that purpose semi-quantitative conversion tables were prepared, which relate each land capability class with specified values of selected land features (see Tables 4.1-4.6). These selected features are a mixture of properties and land qualities. However the concept of land qualities was not explicitly used.

b) More attention should be given in land capability assessment to the factor 'climate'. In several Latin American countries the bio-climatic life zones have been mapped according to Holdridge's method. In Venezuela (Ewell and Madriz, 1968) 22 such life zones have been distinguished. The semi-quantitative conversion tables relating land features with land capability were prepared for each life zone to take into account the interactions between the climate and the other features of the land that influence land capability and land use performance.

A certain value of a particular property/quality does not always have the same influence on land use performance. This becomes clear when comparing the influence of the property 'soil depth' in Tables 4.4. and 4.5. It seems that soil depth class 3 limits land capability in a dry tropical climate to capability class V, whereas in a humid tropical climate the same depth class only limits to class III. From this example it can be deduced that soil depth has a modifying effect on the water regime. However, the conversion tables do not consider the land quality 'available water' directly although this would have been a more functional approach to what is probably the most important problem for land use in Venezuela given the objectives of COPLANARH - the planning of water resource use till the year 2000.

c) The management level described in the USDA system is not consistent with Venezuelan agriculture. In particular, land management and land improvement practices that are supposed to be feasible in the USA require a more subtle treatment in Venezuela because of the wider range in socio-economic land use conditions. Therefore a distinction has been proposed in two technological levels, which splits the land utilization types into two groups:

- *Land utilization types of normal technological level*, which do not include irrigation or drainage, but which may include a wide range of practices such as the use of fertilizers, pesticides, conservation practices, machinery etc. In fact this could be any type of agriculture, but without irrigation or drainage.

- *Land utilization types of improved technological level*, which includes irrigation and drainage, in combination with intensive fertilizer use, pest and disease control, weed control, conservation practices, machinery etc. It is assumed that land use is permanent, and that such land use has a higher productivity than the types with a normal technological level.

Since the influence of land properties/qualities on land use performance depends on the technological level, separate conversion tables have been prepared for the two technological levels (see Tables 4.3-4.6).

Following Brazilian methodology, the possibilities for land improvement have been rated at three levels:

improvement is easily feasible

improvement is feasible

improvement is hardly or not feasible

This rating does not influence the land suitability class, and is therefore not mentioned in the conversion tables (contrary to the Brazilian method, see Section 4.3.4.).

Although the proposed modifications succeed in meeting several criticisms about the applicability of the USDA Land Capability System in developing countries, the Venezuelan method cannot meet the objectives of a specific purpose land evaluation. It is a general purpose physical land evaluation, but with possibilities for development into a specific purpose land evaluation, once the land utilization types have been defined at a more disaggregated level, and once a more functional approach is made when selecting the limiting land characteristics (in particular the land qualities 'availability of water' and 'rainfall probability'). This improved technological level supposes irrigation and/or drainage.

However in most of the life zones where water is a limiting factor rainfed agriculture will probably remain a reality. On the other hand there are areas, such as in the Andean life zones, where normal technology does not include all the practices listed as 'normal'. Therefore the construction of conversion tables for rainfed cultivation of specified (groups of) crops at various technological levels could be a first step towards developing a specific purpose land evaluation. Another type of land utilization of high priority for the conditions prevailing in Venezuela is grazing for beef production. In the conversion tables attention should be given to yield data to provide a quantitative background to socio-economic interpretations of the physical land evaluation results.

Table 4.1 Land capability classification and survey scale

Type of study	Recommended publishing scale	Taxonomic units to be shown	Interpretation units to be shown	
			denomination	examples of symbols
broad vision	< 1:250 000	orders and sub-orders, phases, associations, undifferentiated units, miscellaneous types	capability classes, associations and groups of classes	III - V/VI A (I and II) B (III and IV)
reconnaissance	1:75 000 to 1:150 000	sub-orders, great groups and sub-groups, phases associations, undifferentiated units, miscellaneous types	general capability sub-classes associations	III S - V S/VI SD
semi-detailed	1:25 000 to 1:75 000	families, series, phases associations, undifferentiated units, miscellaneous types	specific capability sub-classes associations	III f - V hs/VI ga
detailed	> 1:10 000	series, types, phases, complexes and some undifferentiated units and miscellaneous types	capability units associations	III f 3 - V h 3 S 2/ VI g 4 a 1

Source: Comerma and Arias, 1971

Table 4.2 The rating of soil properties and land qualities

	1	2	3	4	5	6
Slope (p) %	0 - 3	3 - 8	8 - 20	20 - 45	45 - 60	>60
Micro-relief (m)	level	widely spaced undulations	undulations of equal width & depth	undulations of greater depth than width		
Erosion (e)	slight	moderate	strong	severe		
Texture or granulometry (g)	a - af	Fa - F - FAa	FL-FAL-FA-L	AL - Aa - A		
Stoniness or rockiness (r)	slight	moderate	strong	severe		
Depth in cm (h)	+ 100	50 - 100	25 - 50	0 - 25		
Salts (s)	slight	moderate	strong	severe		
Fertility (f)	slight	moderate	strong	severe		
Permeability or conductivity (c)	v. slow	slow	moderate	rapid		
Internal drainage or groundwater levels (n)	v. slow	slow	moderate	rapid		
External drainage or ponding (a)	v. slow	slow	moderate	rapid		
Inundation (i)	none	occasional	frequent	v. frequent		

Source: Comerma and Arias, 1971

Table 4.3 Conversion table for land capability classification.
Humid tropical forest ecological zone, present land conditions

Life zone	Precipitation (mm)	Temperature (°C)	ETP/P	Altitude (m a.s.l.)
humid tropical forest	1 800 - 3.8 0	more than 24	0.45 - 0.90	0 - 1 000

Factor	Topography T		Erosion E	Soil S						Drainage D		
	slope p	micro-relief m	erosion e	texture g	stoniness r	depth h	salinity s	fertility f	permeability c	internal n	external a	inundation i
Class	up to			accepts	up to				accepts			up to
I	1	1	1	2, 3	1	1	1	1	3	3, 4	3	1
II	2	1	1	2, 3	2	2	2	2	3, 4	3, 4	3, 4	1
III	2	2	2	1 - 3	2	3	2	2	2 - 4	3, 4	2 - 4	2
IV	3	2	2	1 - 3	2	3	2	3	1 - 4	2 - 4	2 - 4	2
V	3	2	3	1 - 4	3	3	2	3	1 - 4	2 - 4	2 - 4	2
VI	4	3	3	1 - 4	3	4	3	4	1 - 4	1 - 4	1 - 4	3
VII	5	3	4	1 - 4	4	4	4	4	1 - 4	1 - 4	1 - 4	3
VIII	6	4	4	1 - 4	4	4	4	4	1 - 4	1 - 4	1 - 4	4

Source: Comerma and Arias, 1971

Table 4.4 Conversion table for land capability classification.
Humid tropical forest ecological zone, improved land conditions

Life zone	Precipitation (mm)	Temperature (°C)	ETP/P	Altitude (m a.s.l.)
humid tropical forest	1 800 - 3 800	more than 24	0.45 - 0.90	0 - 1 000

Factor	Topography T		Erosion E	Soil S						Drainage D		
	slope p	micro-relief m	erosion e	texture g	stoniness r	depth h	salinity s	fertility f	permeability c	internal n	external a	inundation i
Class	up to			accepts	up to				accepts			up to
I	1	1	1	2, 3	1	1	1	1	3	3, 4	3	1
II	2	1	1	2, 3	2	2	1	2	3, 4	3, 4	3, 4	1
III	2	2	2	1 - 3	2	2	2	2	2 - 4	3, 4	3, 4	2
IV	3	2	2	1 - 4	2	3	2	2	1 - 4	2 - 4	2 - 4	2
V	4	2	2	1 - 4	3	3	2	3	1 - 4	2 - 4	2 - 4	2
VI	5	3	3	1 - 4	3	4	3	4	1 - 4	2 - 4	2 - 4	3
VII												
VIII												

Source: Comerma and Arias, 1971

Table 4.5 Conversion table for land capability classification.
Very dry tropical forest ecological zone, <u>present</u> land conditions

Life zone	Precipitation (mm)	Temperature (^{o}C)	ETP/P	Altitude (m a.s.l.)
very dry tropical forest	500 - 1 000	23 - 29	2 - 4	0 - 600

Factor	Topography T		Erosion E	Soil S						Drainage D		
	slope p	micro-relief m	erosion e	texture g	stoniness r	depth h	salinity s	fertility f	permeability c	internal n	external a	inundation i
Class	up to			accepts	up to				accepts			up to
I												
II												
III	1	2	2	2, 3	2	2	1	2	2, 3	2, 3	2, 3	2
IV	2	2	2	2 - 4	2	2	2	2	2 - 4	2, 3	2, 3	2
V	3	2	2	1 - 4	2	3	2	2	1 - 4	2 - 4	1 - 4	2
VI	4	3	3	1 - 4	3	3	3	3	1 - 4	1 - 4	1 - 4	3
VII	5	3	4	1 - 4	3	4	3	3	1 - 4	1 - 4	1 - 4	3
VIII	6	4	4	1 - 4	4	4	4	4	1 - 4	1 - 4	1 - 4	4

Source: Comerma and Arias, 1971

Table 4.6 Conversion table for land capability classification.
Very dry tropical forest ecological zone, improved land conditions

Life zone	Precipitation (mm)	Temperature (^{o}C)	ETP/P	Altitude (m a.s.l.)
very dry tropical forest	500 - 1 000	23 - 29	2 - 4	0 - 600

Factor	Topography T		Erosion E	Soil S						Drainage D		
	slope p	micro-relief m	erosion e	texture g	stoniness r	depth h	salinity s	fertility f	permeability c	internal n	external a	inundation i
Class	up to			accepts	up to				accepts			up to
I	1	1	1	2, 3	1	1	1	1	3	3	2, 3	1
II	1	1	1	2, 3	1	2	1	2	2, 3	2, 3	2, 3	1
III	2	2	2	2 - 4	2	2	1	2	2 - 4	2 - 4	2 - 4	2
IV	3	2	2	1 - 4	2	3	2	2	2 - 4	2 - 4	2 - 4	2
V	4	2	2	1 - 4	3	3	2	3	1 - 4	2 - 4	2 - 4	2
VI	5	3	3	1 - 4	3	4	3	3	1 - 4	1 - 4	1 - 4	3
VII												
VIII												

Source: Comerma and Arias, 1971

4.3.2 Nicaragua: combining general purpose with specific purpose land evaluation

Under the supervision of several US consultant firms the Tax Improvement and Natural Resources Inventory Project of Nicaragua has carried out a semi-detailed soil survey (scale 1:20 000) of the Pacific Region. The resulting map and report on Soils, Their Use and Management (Nicaragua, 1971) is very interesting because of the emphasis placed on data interpretation. Approximately 600 soil series and types were distinguished during the soil survey and were interpreted firstly according to the USDA Land Capability System (Klingebiel & Montgomery, 1961), which resulted in their grouping into the usual eight classes. Subclasses were made to indicate the nature of the limiting factors:

- e - erosion
- w - excess of water
- s - root zone limitations

Topographic or climatic subclasses were not used, but climatic conditions were shown on a life zone map that combines climate and vegetation according to the Holdridge system, similar to the method mentioned for Venezuela. An isohyet map was also included showing the precipitation data during the period May-November, when 85-97% of the rain falls. 66 land capability units (lcu) were identified. Each lcu is comprised of soil/land (mapping) units of the same class and subclass which are supposed to have similar potential and continuing conservation limitations and hazards.

The report (Nicaragua, 1971, p. II-124) states:

> The soils of a capability unit are sufficiently uniform to produce similar kinds of cultivated crops and pasture plants with similar management practices; require similar conservation and management practices under the same kind and condition of vegetative cover, and have comparable potential productivity.

In Venezuela and Brazil it has been recognized that the US-type management practices underlying the land capability classifications may not correspond with the socio-economic and technical conditions of the local farmers. But in Nicaragua this is not the case: therefore one must be careful when applying the Nicaraguan interpretation of land capability, particularly for taxation purposes (which was the purpose of the Nicaraguan study). On the other hand, the report does include a wealth of other information on how to use and manage the soils, which goes far beyond the amount of such information normally found in soil survey reports in Latin America.

Apart from tax assessors, the potential users of this information are expected to comprise: agricultural research stations, farmers, ranchers, agricultural corporations, agricultural extension workers, agricultural supply and services corporations, banks and other loan agencies, engineers and educational institutions. The ultimate objective of supplying them with the information about the land capability is of course the planning of optimal land use, higher crop yields and better soil conservation.

The Nicaraguan study is an example of mixing general purpose land evaluation with specific purpose land evaluation. The US Land Capability Classification represents a general purpose land evaluation system. The resulting classes, subclasses and units all correspond to the assumptions and criteria specified for that system. The Nicaraguan report is remarkable in that the 66 land capability units are maintained as homogeneous (land) units for a specific purpose land suitability classification (see Tables 4.7 and 4.8).

Table 4.7 Crop adaptation by capability units

CAPABILITY UNITS	INTERTILLED ANNUAL ROW CROPS											SOLID-PLANTED ANNUAL CROPS			PERENNIAL ROW CROPS						SOLID-PLANTED PERENNIAL CROPS		SPECIALTY CROPS		
	LOW-VOLUME RESIDUE RETURNING							HIGH-VOLUME RESIDUE																	
	SESAME	PEANUTS	CORN (forage)	SORGHUM (forage)	TOBACCO	VEGETABLES		COTTON	CORN (grain)	SORGHUM (grain)	CASSAVA	RICE		KENAF	SUGARCANE		BANANAS		PLANTAINS		PASTURE		COFFEE	CITRUS	
	UN	UN	UN	UN	UN	UN	IR	UN	UN	UN	UN	UN	IR	UN	UN	IR	UN	IR	UN	IR	UN	IR	UN	UN	IR
I-1	1 A	1 A	1 A	1 A	2 A	2 A	1 A	1 A	1 A	1 A	1 A	2 A	1 B	2 A	2 A	1 A	3 A	1 A	2 A	1 A	2 A	1 A	4 A	3 A	2 A
IIe-1	1 B	1 B	1 B	1 B	2 B	2 B	1 A	1 B	1 B	1 B	1 A	2 B	1 B	2 B	2 A	1 B	3 A	1 A	2 A	1 A	2 A	1 A	4 A	3 A	2 A
IIIe-1	1 C	1 C	1 C	1 C	2 C	2 C	1 B	1 C	1 C	1 C	1 B	2 C	1 C	2 C	2 B	1 C	3 B	1 B	2 B	1 B	2 A	1 B	4 A	3 A	2 B
IVe-1	1 D	1 D	1 D	1 D	2 D	2 D	1 C	1 D	1 D	1 D	1 C	2 D	1 D	2 D	2 C	1 D	3 C	1 C	1 C	1 C	2 A	1 C	4 B	3 B	2 C
IIe-2.1	1 B	1 B	1 B	2 B	2 B	2 B	1 A	1 B	1 B	1 B	1 A	3 B	1 B	2 B	2 A	1 B	3 A	1 A	2 A	1 A	2 A	1 A	4 B	3 B	2 A
IIe-2.2	1 B	2 B	2 B	2 B	3 B	3 B	1 B	2 B	2 B	1 B	2 A	4 B	1 D	2 B	3 A	2 B	4 A	2 C	3 A	2 C	2 A	1 A	4 A	3 A	2 A
IIIe-2a	2 B	2 B	2 B	2 B	3 B	3 B	2 B	3 B	2 B	2 B	3 A	3 B	2 D	3 B	3 A	2 C	4 A	2 C	4 A	3 C	2 A	1 B	4 A	3 A	2 A
IIIe-2	1 C	1 C	1 C	1 C	2 C	2 C	1 C	1 C	1 C	1 C	1 B	3 C	1 D	2 C	3 B	2 C	4 B	2 C	3 B	2 C	2 A	1 B	4 A	3 A	2 B
IVe-2	1 D	1 D	2 D	2 D	2 D	2 D	1 D	2 D	2 D	2 D	2 C	3 D	2 D	2 D	3 C	2 D	4 B	2 D	3 B	2 D	2 A	1 C	4 B	3 B	2 C
IVs-2	4 C	4 C	4 C	4 C	4 C	3 C	4 C	4 C	4 C	4 C	3 D	4 C	4 C	4 C	4 C	4 C	4 B	3 C	4 B	3 C	2 A	1 C	4 B	3 B	2 C
IIe-3	1 B	3 B	2 B	1 B	3 B	2 B	1 B	2 B	2 B	1 B	2 A	3 B	2 B	2 B	3 A	1 B	4 A	2 A	3 A	2 A	2 A	1 A	4 A	3 A	2 A
IIIe-3a	2 B	3 B	2 B	2 B	3 B	3 B	2 B	3 B	2 B	2 B	3 A	3 B	2 B	3 B	3 A	1 B	4 A	3 A	3 A	3 A	2 A	1 A	4 A	3 A	2 A
IIIe-3.1	1 C	3 C	2 C	1 C	3 C	3 C	1 C	2 C	2 C	1 C	2 B	3 C	2 C	2 C	3 B	1 C	4 B	3 B	3 B	3 B	2 A	1 B	4 A	3 A	2 B
IIIe-3.2	4 C	4 C	3 C	3 C	4 C	3 C	4 C	4 C	3 C	4 C	3 B	2 C	4 C	4 C	3 C	4 C	4 B	4 C	3 B	4 C	2 A	4 B	4 A	3 A	4 B
IVe-3.1	2 D	3 D	2 D	2 D	3 D	3 D	2 D	3 D	2 D	2 D	3 D	3 D	2 D	3 D	3 D	1 D	4 C	4 C	3 C	3 C	2 A	1 C	4 B	3 B	2 A
IVe-3.2	4 D	4 D	3 D	3 D	4 D	3 D	4 D	4 D	3 D	4 D	3 D	2 D	4 D	4 D	3 D	4 D	4 C	4 D	3 C	4 D	2 A	4 D	4 A	4 B	4 A
I-4.1	2 A	2 A	1 A	1 A	2 A	2 A	1 A	1 A	1 A	1 A	2 A	2 A	2 A	2 A	2 A	3 A	2 A	2 A	2 A	2 A	2 A	2 A	4 A	3 A	2 A
I-4.2	2 A	3 A	2 A	1 A	3 A	3 A	1 A	2 A	2 A	2 A	2 A	3 A	2 B	2 A	3 A	1 B	4 A	2 B	3 A	2 B	2 A	2 A	4 A	3 A	2 A
IIe-4.1	2 B	2 B	1 B	1 B	2 B	2 B	1 B	1 B	1 B	1 B	2 A	2 B	2 B	2 B	2 A	2 B	3 A	2 A	2 A	2 A	2 A	1 A	4 A	3 A	2 A
IIe-4.2	2 B	3 B	2 B	2 B	3 B	3 B	1 B	2 B	2 B	1 B	2 A	3 B	2 B	2 B	3 A	2 B	4 A	2 B	3 A	2 B	2 A	1 A	4 A	3 A	2 A
IIIe-4a1	2 B	2 B	2 B	2 B	2 B	2 B	1 B	2 B	2 B	2 B	3 A	2 B	3 B	2 B	2 A	2 B	3 A	3 A	3 A	3 A	2 A	1 B	4 A	3 A	2 A
IIIe-4a2	2 B	3 B	2 B	2 B	3 B	3 B	1 B	2 B	2 B	2 B	3 A	3 B	3 B	2 B	3 A	2 B	4 A	3 B	4 A	3 B	2 A	1 B	4 A	3 A	2 A
IIIe-4.1	2 C	2 C	1 C	1 C	2 C	2 C	1 C	1 C	1 C	1 C	2 B	2 C	2 C	2 C	2 B	1 C	3 B	2 C	2 B	2 C	2 A	1 B	4 A	3 B	2 B
IIIe-4.2	2 C	3 C	2 C	2 C	3 C	3 C	1 C	2 C	2 C	1 C	2 B	3 C	2 C	2 C	3 B	1 C	4 B	2 C	3 B	2 C	2 A	1 B	4 A	3 B	2 B
IVe-4.1	2 D	2 D	1 D	1 D	2 D	2 D	1 D	1 D	1 D	1 D	2 C	2 D	2 D	2 D	2 C	1 D	4 C	2 D	3 C	2 D	4 A	1 C	4 B	3 B	2 C
IVe-4.2	4 D	4 D	2 D	2 D	4 D	3 D	4 D	4 D	3 D	4 D	2 C	1 D	4 D	4 D	3 D	4 C	3 C	4 C	2 C	4 C	1 A	4 C	4 B	3 B	4 C
I-5	1 A	2 A	1 A	1 A	1 A	2 A	1 A	1 A	1 A	1 A	1 A	2 A	1 B	2 A	2 A	1 A	3 A	1 A	2 A	1 A	2 A	1 A	4 A	3 A	2 A
IIe-5.1	1 B	2 B	1 B	1 B	2 B	2 B	1 A	1 B	1 B	1 B	2 B	2 B	1 B	2 B	2 A	1 B	3 A	1 A	2 A	1 A	2 A	1 A	4 A	3 A	2 A
IIe-5.2	1 B	2 B	2 B	2 B	3 B	3 B	1 B	2 B	2 B	1 B	2 B	3 B	1 C	2 B	3 A	1 B	4 A	1 B	3 A	1 B	2 A	1 B	4 A	3 A	2 A
IIIe-5a	2 B	2 B	2 B	1 B	2 B	3 B	2 B	2 B	2 B	1 B	2 B	2 B	2 C	2 B	3 A	2 B	4 A	2 B	3 A	2 B	2 A	1 B	4 A	3 A	2 A
IIIe-5	1 C	1 C	1 C	1 C	2 C	2 C	1 C	1 C	1 C	1 C	1 C	2 C	1 C	2 C	2 B	1 C	3 B	1 B	3 B	1 B	2 A	1 B	4 A	3 B	2 B
IVe-5a	2 C	3 C	2 C	2 C	2 C	3 C	2 C	2 C	2 C	2 C	3 C	3 C	2 C	2 C	3 B	2 C	4 B	3 B	3 B	2 B	2 A	1 B	4 A	3 B	2 B
IVe-5	1 D	2 D	1 D	1 D	2 D	2 D	1 D	1 D	1 D	1 D	2 D	2 D	1 D	2 D	2 C	1 D	3 C	1 C	3 C	1 C	2 A	1 C	4 B	3 B	2 C
I-6	2 A	2 A	1 A	1 A	2 A	2 A	1 A	2 A	1 A	1 A	1 A	2 A	1 B	2 A	2 A	1 A	2 A	1 A	2 A	1 A	2 A	1 A	1 A	1 A	1 A
IIe-6	2 B	2 B	1 B	1 B	2 B	2 B	1 B	2 B	1 B	1 B	1 A	2 B	1 B	2 B	2 B	1 B	2 A	1 A	2 A	1 A	2 A	1 A	1 A	1 A	1 A
IIIe-6	2 C	2 C	1 C	1 C	2 C	2 C	1 C	2 C	1 C	1 C	1 B	2 C	1 C	2 C	2 C	1 C	2 B	1 B	2 B	1 B	2 A	1 B	1 A	1 A	1 A
IVe-6	2 D	2 D	1 D	1 D	2 D	2 D	1 D	2 D	1 D	1 D	1 C	2 D	1 D	2 D	2 D	1 D	2 C	1 C	2 C	1 C	2 A	1 B	1 B	1 B	1 C
IVe-7	3 A	3 A	4 A	3 A	4 A	4 A	3 A	4 A	4 A	3 A	3 A	4 A	3 B	4 A	4 D	3 A	4 A	3 B	4 A	3 B	2 A	2 B	4 A	4 A	3 B
IIIw-1	3 A	3 A	3 A	2 A	3 A	3 A	2 A	3 A	3 A	2 A	3 A	1 A	1 A	3 A	2 A	1 A	3 A	3 A	3 A	3 A	2 A	1 A	4 A	3 A	3 A
IIIw-2	3 B	4 B	3 B	2 B	3 B	3 B	2 A	3 B	3 B	2 B	4 A	1 B	1 A	3 B	2 A	1 A	4 A	4 A	4 A	3 A	2 A	1 A	4 A	3 A	3 A
IVw-1	4 A	4 A	4 A	3 A	4 A	3 A	2 A	4 A	4 A	3 A	4 A	2 A	1 A	4 A	2 A	1 A	4 A	4 A	4 A	4 A	2 A	1 A	4 A	4 A	4 A
IVw-2	4 A	4 A	4 A	3 A	4 A	3 A	2 A	4 A	4 A	3 A	4 A	2 A	1 A	4 A	3 A	2 A	4 A	4 A	4 A	4 A	2 A	1 A	4 A	4 A	4 A
IVw-3	3 A	4 A	3 A	3 A	3 A	3 A	2 A	4 A	3 A	3 A	3 A	2 A	1 A	4 A	2 A	2 A	4 A	4 A	3 A	3 A	2 A	1 A	4 A	4 A	4 A
Vw-1	4 A	4 A	4 A	4 A	4 A	4 A	4 A	4 A	4 A	4 A	4 A	3 A	3 A	4 A	4 A	4 A	4 A	4 A	4 A	4 A	3 A	3 A	4 A	4 A	4 A

UN = unirrigated
IR = irrigated

1 = well suited, high yields expected with good management
2 = moderately well suited, average yields expected with good management
3 = poorly suited, low yields even with good management
4 = unsuited, would not survive or yield a harvestable crop

A = no hazard to slight, no special conservation practices needed
B = slight to moderate hazard, one or few conservation practices needed
C = moderate to severe hazard, require special conservation practices or intensive application of simple practices
D = very severe hazard, uneconomical because of the numerous special practices required

Source: Nicaragua, 1971, p.II-193

Table 4.8 Capability units with limited suitability

Capability unit	Pasture	Coffee	Citrus	Mangoes Avocados	Rice
VIe - 1.1	2 B	3 B	2 B	1 B	3 D
VIe - 1.2	2 B	4 B	4 B	3 B	3 D
VIe - 1.3	1 B	4 B	3 B	3 B	3 D
VIe - 2	2 B	1 B	1 B	1 B	3 D
VIe - 3	2 A	4 A	4 A	4 A	3 B
VIs - 1	2 A	4 A	4 A	3 A	4 B
VIs - 2	2 B	4 B	4 B	3 B	4 C
VIs - 3	2 A	4 B	4 B	4 B	4 C
VIw - 1	2 A	4 A	4 A	4 A	3 A
VIw - 2	2 A	4 A	4 A	4 A	3A/1A[1]
VIIe- 1.1	2 C	4 C	4 C	3 C	3 D
VIIe- 1.2	1 C	4 C	3 C	3 C	3 D
VIIe- 2	2 C	1 C	1 C	1 C	3 C
VIIs- 1	3 A	4 A	4 A	4 A	4 A
VIIs- 2	3 B	4 B	4 B	3 B	4 B
VIIs- 3	3 A	4 A	4 A	4 A	4 B
VIIs- 4	3 C	4 C	4 C	4 C	4 D
VIIs- 5	3 B	4 B	4 B	4 B	4 C
VIIw- 1	3 A	4 A	4 A	4 A	3 A
VIIIe-1	4 D	4 D	4 D	4 D	4 D
VIIIs-1	4 D	4 D	4 D	4 D	4 D
VIIIw-1	4 A	4 A	4 A	4 A	4 A

1 = well suited, high yields expected with good management
2 = moderately well suited, average yields expected with good management
3 = poorly suited, low yields even with good management
4 = unsuited, would not survive or yield a harvestable crop

A = no hazard to slight, no special conservation practices needed
B = slight to moderate hazard, one or few conservation practices needed
C = moderate to severe hazard, requires special conservation practices or intensive application of simple practices
D = very severe hazard, uneconomical because of the numerous special practices required

[1] *= with irrigation*

Source: Nicaragua, 1971, p.II-194

The specific purpose land evaluation

Each land capability unit has been classified according to its suitability for specified crops, using a four-class land suitability classification. For some crops a distinction has been made between U- Unirrigated and I- Irrigated.

The land suitability classes have been specified as follows:

class 1: Well suited; high yields expected with good management

class 2: Moderately suited; average yields expected with good management

class 3: Poorly suited; low yields expected with good management

class 4: Unsuited; would not survive or yield a harvestable crop

There are also four subclasses:

A. No hazard to slight; no special conservation practices needed

B. Slight to moderate hazard; one or a few conservation practices needed

C. Moderate to severe hazard; requires special conservation practices or intensive application of simple practices

D. Very severe hazard; uneconomical because of the numerous special practices required

Obviously the separate land suitability classification of each of 600 soil series and types for twenty-three different land utilization types would have been a much more elaborate task than the interpretation of only 66 land capability units. However many combinations of soil series and land utilization types would have been deemed irrelevant at the beginning, thus reducing the number of land suitability analyses that needed to be carried out.

The land suitability classification for specific crops is not supported by a conversion table that specifies and weighs the limiting land properties/qualities taken into account. It is therefore a subjective, qualitative grouping.

There is also a land suitability classification of nine classes for pastures: it does have a conversion table, similar to those mentioned for Venezuela and Brazil (see Table 4.9).

The number of days of grazing and the carrying capacity during the grazing period are the criteria used to distinguish the classes, named in the report 'pasture suitability groups'. The conversion table also lists for each pasture suitability group the corresponding land capability units, their slope, rainfall, and water availability, grazing period, the kind of grasses to be grown (a kind of management specification) and some conservation specifications. It is a very informative table and therefore a good example of data presentation in land evaluation.

Separate conversion tables have also been prepared for potential woodland production.

They relate the various suitability classes (called *management categories* in the report) to limiting land conditions (Table 4.10.) This table can be applied to all the mapping units that correspond to the land capability classes IV, VI, VII or VIII. The range of land conditions corresponding with classes I, II and III have not been included; they are considered to have such a high value for cropland that it would not be economical to use them for woodland. This hypothesis is not supported by the proposals in previous chapters of this report, suggesting that in a physical land evaluation for specific purposes each land utilization type represents a land use alternative in its own right, and that it is not the task of the physical land evaluator to exclude land utilization types from certain land units on economic grounds. The demand for cropland determines whether forestry should operate on non-agricultural land only. There is now increased interest in farming

Table 4.9 Pasture suitability *groups*

Pasture suitability group	Capability units	Slope range (%)	Rainfall range in annual mean (mm)	Grazing period	Days of grazing	Carrying capacity for grazing period A[1] (animal units[2] per manzana)	B[1]	Water availability and source	Pasture grasses	Conservation practices
1	IIIe-3.2, VIe-1.3, IVe-3.2, IVe-4.2	0-30	2000-3000	May to March	270	2	3	abundant, streams and Lake Nicar.	Jaragua, Napier, Guinea, Alemán, Para	overgrazing, control. Field ditches locally
2	IVe-1	0-15	900-2000	Dec.to Aug.	240	2	3	limited, shallow wells	Guinea, Pangola Bermuda, Estrella Para	field ditches, drainage main or lateral if needed
3	I-1, I-5, I-6, IIe-1, IIe-2.1, IIe-6, IIIe-1	0-8	1400-2000	June to Jan.	210	1	3	limited, deep wells	Jaragua, Napier, Pangola, Guatemala, Buffalo	none
4	IIe-1, IVe-2, IIIe-2	0-15	1100-2000	June to Jan.	210	1	2	limited, springs and wells	Jaragua, Guinea, Pangola, Napier, *Japanese, Guatemala,* and Bermuda	field ditches, drainage main or lateral if needed
5	I-4, I-4.2, IIe-2.2, IIe-3,IIe-4.1, IIe-4.2, IIe-5.1,IIe-5.2, IIIe-2a,IIIe-2,IIIe-3a, IIIe-3.1, IIIe-4a1, IIIe-4a2,IIIe-4.1, IIIe-4.2,IIIe-5a, IIIe-5,IIIe-6,IVe-1, IVe-2,IVe-3,IVa-4.1	0-15	1000-2000	*June to Jan.*	180	1	2	limited, deep wells	Jaragua, Guinea, Napier, Buffalo	overgrazing control
6	VIe-1	0-15	800-1500	Dec.to June	180	0.5	1.5	abundant, streams and shallow wells	Bermuda, Para, Estrella	field ditches, for drainage and soil reduction
	VIIe-1	0-15	800-1500	Dec.to June	180	0.25	0.75			
7	Ve-2, Ve-5a, Ve-5 IVe-6, IVe-7, VIe-1, VIe-1.2, VIe-2, VIe-1	8-30	1000-2000	June to Nov.	180	0.5	5	limited, deep wells	Jaragua, Guinea Buffalo, Bermuda, Napier	overgrazing control. Grass waterways. Structural outlet or gully control where needed
8	IVe-3, VIe-2,Ve-1	0-15	1000-2000	June to Nov.	180	0.5	1	limited streams, or wells	Jaragua, Alemán	drainage ditches
9	VIe-1, VIe-2,VIe-3, VIe-3, VIIe-1, VIIe-1.2,VIIe-4, VIIe-2,VIIe-3, VIIe-4, VIIe-5	0-75	1000-2000	June to Nov.	190	0.25	0.75	very limited, must be piped	Jaragua, Guinea, *Buffalo*	structural outlet or gully control Overgrazing control

[1] A Present common management
[1] B Improved management
(to convert to carrying capacity per hectare, multiply by 1.4)
[2] One animal unit is equalto a cow and calf, bull, or one mature horse

Source: Nicaragua, 1971, p.II-275

Table 4.10 Potential woodland production

Soil, climate, and other factors	Management category				
	Bpr	Bpp	Bp_1	Bp_2	Bp_3
LIFE ZONE:					
Humid province	any province	any province	humid, prehumid, superhumid	all above	all above plus subhumid
Latitude and altitude region	any	any region	lower montane premontane subtropical tropical	all above plus montane	all above
MONTHS EFFECTIVELY DRY (1)			1-3	1-5	1-7
ANNUAL RAINFALL (mm)	2000 + 4000 +	500 + 1000 + (2) 2000 +			
SLOPE GRADIENT %	F,G,50+ G,75+	G,75+ F,G,50+ F,G,50+	0-30 A-E	0-50 A-F	0-75 A-F
EROSION SUSCEPTIBILITY	high any	high high moderate	no E	no E	any
SOIL DEPTH	any	any	deep to moderately shallow 1-3	deep to shallow 1-4	any
TEXTURE:					
Surface	any	any	1-5	2-6	any
Subsoil	any	any	0-5	any	any
DRAINAGE	any	any	1-3	1-4	any
LIMITATIONS/ RESTRICTIONS	any	any	no.ii,ww, ss,sso or GG	no.ii or restrict. 1,5 or 6 (3)	any
POTENTIAL YIELD (Cu.mts.m/ha/yr)(4)	no logging	0.5-2 (25% of total yield)	15+	5-14	2-8

(1) *An "effectively dry month" is defined as a month during which the soil moisture reserve is down to 50 percent of field capacity or, when such information is not available, a month with less than 50 mm of rainfall*

(2) *Also, if two consecutive months together have more than 500 mm of rainfall*

(3) *Except where hardpans or impermeable layer are covered by 60 cm or more of soil*

(4) *Based on a 25-year growing period for best adapted species*

Source: Nicaragua, 1971, p.II-292.

systems that mix crops with forestry. Particularly in Latin America, where (in some countries) there are vast land reserves and the present productivity of crops is very low, there is no reason to limit the land suitability classification for forestry purposes to those lands that are unsuitable for crops.

The management categories (our land suitability classes) have been defined as follows:

Bp 1 Production forest land: Land with a capacity for a high level of yield through intensively managed plantations or highly controlled natural regeneration and with favourable logging conditions

Bp 2 Production forest land: Land with a capacity for moderate yields and/or with adverse logging conditions

Bp 3 Production forest land: Land with a capacity for a low level of yield through extensive management and/or with adverse logging conditions

Bpp Protection-production forest land: Land on which the protection function of the vegetation is of highest priority, but on which a portion of the trees can be removed periodically by means of a selective, highly controlled system of logging

Bpr Protectional forest land: Land on steep slopes with erodable soils and high or intense rainfall on which any major disturbance of the vegetation would risk destructive flooding and/or depletion of the soil base

Management and conservation specifications (inputs)

The land capability units are the model for the land conditions, not only in the land suitability classification for specific crops, but also for the specification of management and conservation practices. The latter is consistent with the purpose of the land capability units in the USDA system. Separate tables have been presented for cotton, maize, sorghum, sugar cane (irrigated and unirrigated), rice (irrigated and unirrigated), banana, plantain (irrigated and unirrigated), and coffee that specify recommended management practices, e.g. seedbed preparation, planting, irrigation, insect control, harvesting, for several combinations of land capability units (see Tables 4.11. and 4.12 which refer to sugar cane). Only a few sets of land capability units have been distinguished, varying from five sets (cotton) to only one set (unirrigated plantain). In the tables a distinction is made between two management levels: present common practices and improved practices.

It is surprising that management level is considered at such a late stage of land evaluation, after the land capability/suitability groupings have already been made. It would have been more in agreement with the proposals made in previous chapters of this report to make separate land capability/suitability groupings for different management levels right from the start, distinguishing between land utilization types dedicated to producing the given crops with present practices and with improved practices.

Soil conservation practices have been presented in a table (Table 4.13). This table distinguishes more land conditions (20 sets/combinations of land capability units) than the table that specifies the management practices. This greater emphasis on conservation than on management specifications is consistent with the primary objective of the USDA Land Capability Classification: soil conservation.

For each set of land capability units several sets of 'adapted crops' have been distinguished with different conservation requirements,

Table 4.11 Non-irrigated sugar cane production practices by capability units

Practice of operation	management level	
	LEVEL A (present common practices)	LEVEL B (improved practices)
SET 1: Management recommendation for capability units: I-1, I-4.1, I-5, IIe-1, IIe-2.1, IIe-2.2, IIe-3, IIe-4.1, IIe-5.1, IIIe-4a1, IIIe-4a2, III-1 (no erosion to moderate erosion hazard)		
Seedbed preparation	same as for irrigated sugar cane	same as for irrigated sugar cane
Planting - varieties	POJ, Purple, Pinder	POJ, Purple, Pinder
- rate	same as for irrigated sugar cane	same as for irrigated sugar cane
- date	May, June	May, June
Cultivation	blade once, cultivation 2 or 3 times, machete 3-4 times	cultivator 3 or 4 times. Machete 4-5 times
Fertilization	none	200 lbs urea and 100 lbs 10-40-10 in June, July
Disease control	resistant varieties used	resistant varieties used
Insect and pest control	none	2 or 3 applications of insecticides against little bugs, armyworms, stalk borer
Trash disposal	after harvest, trash piled in alternate rows away from base of plant. This controls weeds in every second row reducing cultivation costs by half	after harvest, trash piled in alternate rows away from base of the plant. This controls weeds in every second row reducing cultivation costs by half
Harvesting	by hand when cane reaches maturity, from November to May	by hand when cane reaches maturity, from November to May
Replanting	from 3 to 5 years, depending on yields	from 3 to 5 years, depending on yields
SET 2: Management recommendation for capability units: IIIe-1, IIIe-3, IIIe-4.1, IIIe-5a (slight erosion hazards)		
Planting	cane planted on contour	cane planted on contour
All other practices	same as for Set 1 above	same as for Set 1 above

Source: Nicaragua, 1971, p.II-204

Table 4.12 Irrigated sugar cane production practices by capability units

SET 1: Management recommendation for capability units: I-1, I-4.1, I-4.2, I-5, IIe-2.1, IIe-3, IIe-4.1, IIe-4.2, IIe-5.1, IIe-5.2, IIIe-3e, IIIa-5e
(no erosion to slight erosion hazard)

Practice of operation	management level	
	LEVEL A (present common practices)	LEVEL B (improved practices)
Seedbed preparation	beginning of dry season. Deep plowed, disk harrow twice, furrowed. Furrowing equipment less effective than in B. Furrow 5 feet apart.	beginning of dry season. Deep plowed, disk harrow twice furrowed. Special furrow machine to make furrows 6" to 12" deep and 5 feet apart.
Preparation for irrigation	irrigation laterals and sublaterals are revived with large moldboard ditches; connections to permanent canals repaired by hand	irrigation laterals and sublaterals are revived with large moldboard ditches; connections to permanent canals repaired by hand
Planting - varieties	varieties: CP-44155, Houston 41223, LS-143, Pindar, NKO-3-10	Varieties: CP-44155, Houston 41223, LS-143, Pindar, NKO-3-10
- rate	2.5 to 4 tons/mz.planted continuously in the furrow with hand labour	2.5 to 4 tons/mz,planted continuously in the furrow with hand labour
- date	early in dry season, as soon as land is prepared	early in dry season, as soon as land is prepared
Cultivation	4-6 cultivations, machete in the row as required	pre-emergence herbicides used. Post-emergence herbicides used along with 2 or 3 cultivations. Machete weeding in rows, as required. In second and subsequent years, special plow is run on either side of cane row, shortly after harvest, very close to cane to tear away part of the stools and to trim roots
Fertilization - 1st year	at planting time 200 lbs 10-40-10, if phosphorus required; 150 lbs urea two moths after planting and 150 lbs urea in June or July	at planting time 200 lbs 10-40-10, if phosphorus required; 150 lbs urea two months after planting and 150 lbs urea in June or July.
- subsequent years	150 lbs urea right after harvest. If required 10-40-10 is also applied at this time. 150 lbs urea three to four months after harvesting	150 lbs urea right after harvest. If required 10-40-10 is also applied at this time. 150 lbs urea three to four months after harvesting
Irrigation	surface irrigation, longer interval between applications than in B	surface irrigation, 6-12 days intervals
Disease control	disease-resistant varieties planted	disease resistant varieties planted
Insect and pest control	4 to 6 spray applications to control insects. Main insects - spittle bugs, armyworms, stalk borers Rats controlled with poison baits.	4 to 6 spray applications to control insects. Main insects - spittle bugs, armyworms, stalk borers Rats controlled with poison baits.
Harvesting	beginning of dry season. Earlier maturing varieties harvested first. Selection of area to harvest is made by checking age of plant, its appearance, and chemical analyses for total solids and sugar. Cane burned prior to being harvested to reduce harvest costs. Irrigation discontinued one month before harvest. Harvesting done by hand.	beginning of dry season. Earlier maturing varieties harvested first. Selection of area to harvest is made by checking age of plant, its appearance, and chemical analyses for total solids and sugar. Cane burned prior to being harvested to reduce harvest costs. Irrigation discontinued one month before harvest. Harvesting done by hand.
Replanting	from 3 to 7 years, depending on yields	from 4 to 10 years, depending on yields

SET 2: Management recommendation for capability units: IIIw-2, IVe-1, IVe-2
(little or no erosion hazard but drainage problem)

Planting	same as for SET 1 above except that cane is planted on the ridge	same as for SET 1 above except that cane is planted on the ridge
All other practices	same as for SET 1 above	same as for SET 1 above

NOTE: mz = manzana; 1 manzana = 0.7 hectares

Source: Nicaragua, 1971, p.II-204

resulting in distinct conservation specifications. The sets of crops distinguished are:

- A 1 Intertilled annual row crops (corn, cotton, sesame, sorghum, peanuts, vegetables, tobacco, cassava. Solid-planted crops
- B 1 Perennial row crops (bananas, plantains, sugar cane)
- B 2 Perennial solid-planted crops (pastures)
- C 1 Coffee

The table also refers to the urgency for implementing conservation practices specified if the sets of crops mentioned are grown:

- E Practice essential for soil and water conservation
- O Practice essential only if on-site inspection shows need
- X Practice desirable but not essential for soil conservation
- F Practice applies only to certain kinds of crops in group

It is surprising that the table does not show any correlation between the urgency of soil conservation practices and the class levels; for example the classes II, III, and IV apparently have the same need for gradient terrace systems when cultivated with crop sets A or B 1.

Yield potential (outputs)

Whereas the land capability units have been given the central role in the land suitability classification and in the specifications of management and conservation practices, they have not been considered as the most detailed land (mapping) units for yield prediction. Tables are presented specifying the yield potential of each soil (mapping) unit.

Table 4.13 Conservation practices by capability unit

CONSERVATION PRACTICES / CAPABILITY UNITS	I-1 I-5			I-6		I-4.1 I-4.2			IIe-1 IIe-2.1 IIe-5.1 IIe-5.2			IIe-2.2 IIIe-2a			IIe-3 IIe-4.1 IIe-4.2			IIe-6 IIIe-6			IIIe-1 IIIe-2 IIIe-5			IIIe-3a IIIe-3.1 IIIe-4a1 IIIe-4a2 IIIe-4.1 IIIe-4.2 IIIe-5a			IIIw-1			IIIw-2 IVw-1 IVw-2 IVw-3		IIIe-3.2 IVs-2 IVe-3.1 IVe-3.2 IVe-4.1 IVe-4.2 IVe-7	IVe-1 IVe-2 IVe-5		IVe-5a		IVe-6 VIe-2		Vw-1 VIw-1 VIw-1	VIw-2		VIe-1.1 VIe-1.2 VIe-1.3 VIe-3 VIs-1 VIs-2 VIs-3	VIIe-2		VIIe-1.1 VIIe-1.2 VIIs-1 VIIs-2 VIIs-3 VIIs-4 VIIs-5
ADAPTED CROPS	A1	B1	B2	C(1)*	B2	A1	B1	B2	A1	B1	B2	A1	B1	B2	A1	B1	B2	A1	B2	C(1)*	A1	B1	B2	A1	B1	B2	A1	B1	B2	B1	B2	B2	B1	B2	A1	B2	C(1)	B2	B2	A1+	B2	B2	C(1)	B2	B2
SIMPLE CONSERVATION PRACTICES																																													
CROP ROTATION	X					X			X			E			X			X			X			X			X								E										
CROP RESIDUE USE	X	X				E	X		E	X		E	X		E	X		E			E	X		E	X		E	X		X			X		E					X					
CROP RESIDUE MULCHING	X	X		X		X	X		X			X			X			X			X			X			X								X										
COVER AND GREEN MANURE CROP	X	X				X	X		X			E			X			X			O			E			X								E										
FERTILIZING	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
MINIMUM TILLAGE	E					E			E			E			E			E			E			E			E								E										
SUBSOILING	O					O			O			O			O			O			O			O			O								O										
TWO-WAY TILLAGE	X					X			X			X			X			X			X			X			X								X					X					
CONTOUR FARMING	X					X			E			E			E			E			E			E									E		E										
SPECIAL CONSERVATION PRACTICES																																													
WATER EROSION CONTROL PRACTICES																																													
BENCH TERRACE																																					O						X		
GRADIENT TERRACE SYSTEM	O								E			E	F		E	F		E			E	F		E	F								E		E										
FIELD DIVERSION									O	O		O	O		O	O		O									O																		
GRASSED WATERWAY OR OUTLET						O			E	O		E	O		E	O		E			E	O		E	O		O								E										
STRUCTURAL OUTLET OR GULLY CONTROL																					O	O	O	O	O	O							O	O	O								O	O	
SEDIMENT BASIN																				X																	O						O		
WIND EROSION CONTROL PRACTICES																																													
WIND STRIP CROPPING	X					X			X			X			X			X			X			X									X												
BUFFER OR WINDBREAK PLANTING		X				X	X		X	X		X	X					X			X												X												
DRAINAGE PRACTICES																																													
FIELD DITCHES																											E	O	O	O	O									O					
DRAINAGE MAIN OR LATERAL																											E	E	X	E	E									O					
IRRIGATION PRACTICES																																													
SPRINKLER	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						X			
FURROW OR CORRUGATION	X	X				X	X		X	X					X	X								X	X		X	X		X															
FLOOD OR BORDER			X					X			X						X												X		X									X	X				
LAND LEVELING OR SMOOTHING	X	X				X	X		X	X					X	X											X	X		X	X									X	X				

A1 Intertilled annual row crops (corn, cotton, sesame, sorghum, peanuts, vegetables, tobacco, and cassava are most common). Applies also to solid-planted crops.

B1 Perennial row crops (bananas, plantains, and sugar cane are most common).

B2 Perennial solid-planted crops (pasture).

C(1) Coffee

E Practice essential for soil and water conservation.

O Practice essential only if on-site inspection shows need.

X Practice desirable but not essential for soil conservation.

F Practice applies to only certain kinds of crops in group.

* Many other crops are adapted to these soils, but because of economics, only coffee is now raised.

+ Only rice with irrigation.

Source: Nicaragua, 1971. p.II-190,191

Climatic variation is not a separate factor in the rating of yield potential; the soil series and types are supposed to be homogeneous in this respect, an acceptable assumption at this scale of land evaluation.

Yields (averages over several years) have been estimated for eight different crops and for pastures. Rice and sugar cane yields have been specified for both irrigated and unirrigated conditions.

A distinction has been made between two levels of management when specifying crop yield:

A-average management
B-improved management

These two levels have been defined as follows:

Management level A:

'farmers who do not use a good cropping system, the best tillage or planting methods, or pest control methods, and optimum amounts and kinds of fertilizers'

Management level B:

'farmers who use such practices as suggested .... in the report'

Conclusions

The role of the land (mapping) units

It may be concluded from the discussion that a preliminary grouping of the many soil (mapping) units into a much smaller (only 10%) number of land units for purposes of data interpretation has some advantages: it simplifies data processing and the presentation of results. All land (mapping) units that belong to the same capability units are considered to be the same for purposes of data interpretation except for yield potential. But this kind of step-wise simplification of the land evaluation into smaller, homogeneous strata of land (mapping) units carries the risk of mixing up different land suitability criteria: those used for the grouping into land capability units, for the grouping into land suitability classes, for the grouping into sets with similar management and/or conservation specifications and finally into sets with similar yield potential.

It seems convenient to make separate interpretations for each land (mapping) unit in connection with each land utilization type that is rated relevant. Data processing of the multiple data should not be a reason for an *a priori* and possibly too arbitrary grouping of land (mapping) units as shown in the Nicaragua report, since data interpretation anyway represents only a fraction of the time and expenses dedicated to the resource survey, the data collection stage. In future, automated data handling for purposes of land evaluation and periodical re-interpretation should be a major concern of this type of study in developing countries too.

The role of the land utilization types

A more systematic approach to the definition of relevant land utilization types would have been valuable for the user of the Nicaraguan report. It would have shown more clearly the relations that exist between the various pieces of information about land capability, land suitability, management, conservation and yield potential. It might also have improved the quality of the interpretations, obliging the reporters to be more problem-oriented and more specific in their conclusions.

The major criticism of the report is that the present land use practices, which were systematically studied when the present land use map was made, have not been considered more carefully in the identification and definition of relevant land utilization types. The only key attributes considered were produce, management and the distinction between irrigated and unirrigated. Management has been dealt with rather superficially at a very late stage of the procedure, when a distinction was made between common and improved management. Only the factor 'produce' was seriously considered at several levels of generalization:

LEVEL A	LEVEL B	LEVEL C[1]
crops	annual intertilled annual solid-planted perennial row perennial solid-planted perennial coffee perennial citrus	sesame peanuts corn (forage) corn (grain) sorghum (forage) sorghum (grain) vegetables tobacco cotton cassava rice kenaf
pasture		
forestry	production forest protection/production forest protection forest	

[1] *only for annual crops*

The question whether the land utilization types and their key attributes in the Nicuraguan land evaluation play a role has been answered in the following scheme:

Key attributes	Suitability classification	Yield prediction	Management specifications	Conservation specifications
produce	LEVEL C	LEVEL C	LEVEL C	LEVEL A/B
irrigated/ unirrigated	YES	YES	YES	YES
management levels A/B	NO	YES	YES	NO

A more systematic application of the land utilization type would suggest the following answers (without referring to other key attributes mentioned in previous chapters but not considered by the Nicaraguan study, such as technological level (the kind of implements used, hand/animal/power-operated equipment, labour intensity, the scale of operations, the land tenure conditions):

Key attributes	Suitability classification	Yield prediction	Management specifications	Conservation specifications
produce	LEVEL C	LEVEL C	LEVEL C	LEVEL C
irrigated/ unirrigated	YES	YES	YES	YES
management levels A/B	YES	YES	YES	YES
other[1]	YES	YES	YES	YES

[1] *e.g. labour, implements, capital, scale of operations, technology*

4.3.3 Mexico: towards a land evaluation for individual crops

CETENAL (the Commission for the Study of the National Territory) has embarked on a very ambitious project: a natural resources inventory of the entire country. The selected scale 1:50 000 is surprisingly large, considering the size of the country (approx. 2 million km^2) and the great expanse of arid and semi-arid low potential zones. The inventory is supported by 1:25 000 coloured aerial photographs. Separate maps are made of the topography, geology, climate, land use and vegetation, soils (slightly modified legend of the FAO/UNESCO World Soil Map), and potential land use.

In this section we will pay attention to the potential land use map. CETENAL adheres strictly in the publication of its series of potential land use maps to the USDA Land Capability System (Klingebiel and Montgomery, 1961). However, in 1973 CETENAL had already published some interesting new proposals for making potential land use maps (Quiñones *et al.*, 1973). The new methods proposed include a general purpose land evaluation and a specific purpose land evaluation, which take into account over a hundred different crops, forage and forestry species.

The reasons why CETENAL has not changed its method of preparing potential land use maps since these new proposals were published are not known to this author. Perhaps it is for reasons of consistency that CETENAL continues to apply the USDA Land Capability System, although the new method has several interesting points as will be explained in this section.

GENERAL PURPOSE LAND EVALUATION

Land qualities/properties and 'agrological capacity' classes

The following land qualities/properties have been considered:

C - water availability
T - slope
P - effective soil depth
O - obstructions (stoniness, rockiness)
I - inundation
S - salinity
N - alkalinity
A - acidity
F - phosphorus fixation
E - present erosion
D - internal drainage

These factors are defined at levels (mostly seven or eight) that correspond to the various land capability classes (see Table 4.14). The land quality 'water availability' is based entirely on the data presented on the climatic map which uses a very detailed climatic classification according to Köppen. No attempt is made to arrive at a more synthetic description of water availability that also takes account of soil factors. Soil depth is rated independently. Other soil properties contributing to the water availability, such as pF and infiltration rate, have not been considered.

A distinction is made in land capability with and without land improvement. The land capability classification for unimproved land conditions is called the 'agrological capacity' classification. In Mexico the stage of data collection and rating of the land qualities/ properties for unimproved conditions is called the 'agrological survey'.

Land improvement and 'potential capacity' classification

To arrive at an evaluation of 'maximum development possibilities' (Quiñones *et al.*, 1973, p. 41) two aspects need consideration:

Table 4.14 Conversion table for rating soil properties and climate in eight classes

LAND QUALITY/PROPERTY	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	CLASS 7	CLASS 8
A. AVAILABLE WATER	Af, Afm (A)Cf, (A)Cfm Cf, Cfm Cfb', Cfmb'	Am, Amf, Aw_2, Aw_2x', Aw_1, Aw_1x' A(C)m, (A)Cmf, $A(C)w_2$, $(A)C(w_2)x'$, $A(C)w_1$, $(A)C(w_1)x'$ Cm, Cmf, $C(w_2)$, $C(w_2)x'$, $C(w_1)$, $C(w_1)x'$ Cmb', Cmfb', $C(w_2)b'$, $C(w_2)x'b'$, $C(w_1)b'$, $C(w_1)x'b'$	Awo, Awox' $A(C)w_0$, $(A)C(w_0)x'$, $C(w_0)$, $C(w_0)x'$, $C(w_0)b'$, $C(w_0)x'b'$	$BS_1h'w$, $Bs_1h'x'$ BS_1hw, BS_1hx' BS_1kw, Bs_1kx' $BS_1k''w$, $BS_1k''x'$			BSohw,BSohx, BSohs,BSohw, BSohx,BSohs, BWhw, BWhx, BWhs, BSokw, BSokx, BSoks, BWkw, BWkx, BWks,BSokw, BSokx, BSoks, BWkw, BWkx, BWks	BWh'w, BWh'x', BWh's, BWhw,BWhx', BWhs,BWkw, BWkx', BWks, BWk"w, BWk"x', BWk"s
B. SLOPE (gentle)	0-2%	2-6%	6-10%	10-15%	15-25%	25-40%	40-100%	>100%
(rolling)		<3%	2-6%	6-10%	10-25%	25-40%	30-100%	>100%
C. EFFECTIVE SOIL DEPTH (cm)	>75	50-75	35-50	25-35	15-25	10-15	<10	
D. OBSTRUCTIONS	<5%	5-10%	10-15%	15-35%	35-50%	50-70%	40-90%	>90%
stones <75 cm	<10%	15-25%	25-35%	35-50%				
stones >75 cm	<5%	5-10%	10-15%	15-35%				
E. INUNDATION	no losses	once in 10 years 0-20% losses	once in 10 years 20-50% losses	once in 10 years >50% losses	no crops only pasture	pasture limited	only occas. pasture	no pasture
F. SALINITY (mmhos/cm)	0-2	2-4	4-8	8-16	>16			
G. ALKALINITY/ SODICITY								
$\%Na^+$	<10	10-15 / >15	15-40	40-60	>60			
pH	<7.5	7.5-8.5						
depth	0-75	0-75 / 75-125	0-75	0-75	0-75			

Source: Adapted from Quiñones et al., 1973

- specification in general terms of recommended land improvement practices
- the effectiveness of these improvements, which can be expressed by the difference between the 'agrological' capacity class (the land capability class without land improvement) and the 'potential' capacity class (the land capability class with improvement). In the Mexican method this effectiveness depends entirely on physical factors; the cost of land improvement is not considered.

The following land improvement practices have been considered:

a - irrigation

l - leaching

p - application of amendments for correcting alkalinity

t - stone removal

c - liming

i - flood control

d - drainage

e - erosion control

Land utilization types

The new CETENAL method does not define the land utilization types considered in the agrological and potential capacity classifications, apart from the usual distinction that is made between agricultural crops (classes 1-4), pastures (classes 5 and 6) and forestry (classes 6-8). There is one reference to the management level in the potential capacity classification (Quiñones *et al.*, 1973, p. 41): 'adequate techniques will be applied for the realization of the mentioned land improvements'.

Definition of agrological and potential capacity classes

The eight classes have not been defined. It has only been stated that from class 1 to class 8 the limitations increase, affecting the number and quality of crops (including forage and forest tree species) that can be grown economically within each climatic/physiographic zone. Criteria such as yield or input requirements have not been considered. Therefore these capacity classes are essentially no more than systematic groupings of land (mapping) units with similar levels of selected land qualities/properties.

Specific purpose land evaluation

The lack of consideration for land utilization types in the general purpose land evaluation has been compensated in the specific purpose land evaluation. In this evaluation the feasibility of growing over one hundred different crops, forage and forestry species is assessed. The single most important land quality considered here is 'water availability'. Conversion tables (using computers for data handling) have been prepared for four broad climatic zones: arid and semi-arid; subhumid; humid with dry season; humid all year round. In each broad climatic zone four temperature regimes have been distinguished: hot; semi-hot; temperate; semi-cold. The water availability in each zone has been rated according to the levels of this land quality distinguished in the general purpose land evaluation (by using subdivisions of Köppen's climatic classification). For each combination of broad climatic zone, temperature regime and level of water availability, the crops that it is feasible to grow have been listed in the conversion table. Examples of such conversion tables are Tables 4.15 and 4.16.

The land evaluation for specific crops also takes into account their requirements for some other land qualities: effective soil depth, salinity, alkalinity, acidity (Table 4.17).

Since hundreds of different combinations of feasible crops may result, a numerical key has been developed in which each combination of feasible crops is indicated by a different number (similar to telephone numbers).

The crops that are classified feasible have been selected on physical grounds only. They are not necessarily relevant from the socio-economic point of view. CETENAL's maps and reports are made primarily for national and regional planning. More detailed physical analyses will be needed regarding crop varieties, management techniques, inputs and outputs, in order to orient more detailed types of land use planning.

The proposed system is a two-class specific purpose physical land evaluation: class I-suitable; class II-not suitable.

Correlation between these two classes and the land capability classes of the general purpose land evaluation may exist, but the system has not been designed to be conclusive about such a correlation. Basically the two land evaluations are separate exercises; this distinguishes them (favourably) from the Nicaraguan example, where the two systems became rather mixed up. If there is a correspondence between general purpose land capability classes and the yields of the crops of the specific purpose land evaluation, this is more likely to be coincidence than a deliberate result of the classification. A more profound comparison of the land qualities/properties and the land requirements of each crop would be needed to arrive at a land suitability classification that is more specific about such fundamental data for land use planning as yields, input requirements, hazards.

The CETENAL report does not explain in detail how the computerized conversion tables for the identification of feasible crops were made. Therefore one is forced to conclude that there is no adequate body of knowledge about the land requirements of the mentioned crops based on on-site agronomic experience, for determining the crop-feasibility within an acceptable margin of accuracy, as the CETENAL report purposes. My impression is that the CETENAL proposals are refreshingly courageous and relevant, as far as methodology is concerned, but that the basic assumptions and the computerized conversion tables need to be examined by a wider circle of specialists who have been asked to help improve the method in successive approximations. The combination of crops into

Table 4.15: Feasible crops, arid and semi-arid regions. Source: Quiñones et al., 1973, tab.14.

	Class 1		Class 2				Class 3	Class 4
HOT	barley castor bean celery chick pea coriander guava mamey tomato	canary seed cashew chayotte citrus grape jicama parsley wheat	aubergine canary seed cucumber lentil millet sesame walnut	barley carrot fig linseed oat soybean watermelon	bean chilli ground nut marron pomme gr. spinach b. wheat	bean brown cotton jute melon rice sweet potato	agave (am.aloe) garlic olive onion pore safflower sisal tamarind	date palm guayule maguey mezcalero maguey tequilero maiz opuntia (nopal) sorghum sunflower
SEMI-HOT	avocado beet cabbage cauliflower chick pea coriander jicama lettuce parsley potato spinach tamarind	barley broccoli canary seed celery citrus grape lentil mamey pea radish strawberry	aubergine carrot chayotte cucumber jute oats rice sweet potato	beet cashew chilli groundnut marron parsley sesame tomato	bean castor bean coriander guava melon plum soybean watermelon	canary seed celery cotton jicama millet pomme gr. spinach beet wheat	agave (am.aloe) almond barley fig garlic linseed olive onion pore safflower sisal tamarind	brown bean chick pea guayule maguey mezcalero maguey tequilero maiz opuntia (nopal) sorghum sunflower
TEMPERATE	apricot asparagus custard ap. strawberry	artichoke cherry rye	apple barley cabbage castor bean chilli groundnut lentil melon peach potato sarac.wheat spinach beet watermelon	apricot beet canary seed cauliflower citrus grape lettuce nut parsley quince sesame sweet potato wheat	aubergine broccoli carrot celery coriander guava mamey oat pear radish soybean tomato white sapote	avocado brown bean cashew chayote cucumber jicama marron pea plum rye spinach turnip	almond bean chick pea fig garlic linseed millet	brown bean chick pea maguey pulquero maiz opuntia (nopal) sorghum
SEMI-COLD	asparagus	cherry	apricot cabbage celery marron peach sarac.wheat sweet potato	beet canary seed chilli oat plum soy bean turnip	broccoli carrot coriander parsley potato spinach wheat	brown bean cauliflower lettuce pea radish spinach beet	barley bean chickpea garlic linseed maiz millet onion pore rye safflower sunflower	maguey pulquero opuntia (nopal)

NOTE: Class 1, 2, 3 and 4 of Tables 4.15 and 4.16 represent decreasing degrees of water availability: class 1 = no water deficiency; class 2 = water deficiency during the winter; class 3 = water deficiency all year round with good prospects for rainfed crops; class 4 = water deficiency all year round with limited prospects for rainfed crops (see also the Köppen climates corresponding with these classes, indicated in Table 4.14). In arid and semi-arid regions irrigation will be needed to create the water availability conditions corresponding with classes 1, 2 and 3. In sub-humid conditions no class 4 water availability conditions have been considered in Table 4.16.

Table 4.16: Feasible crops, sub-humid regions. Source: Quiñones et al., 1971, Table 15.

	Class 1		Class 2		Class 3			
HOT	barley	beet	cocoa	coffee	agave	aubergine	bean	brown bean
	broccoli	cabbage	chayote	citrus	carrot	cashew	chick pea	chilli
	canary seed	cauliflower	guava	jute	cucumber	fig	garlic	groundnut
	cucumber	garlic	kenaf	mango	linseed	maguey tequil.	maguey mezcalero	maiz
	jicama	lentil	papaya	pomme gr.	marron	melon	millet	onion
	lettuce	mammey	rice	ricinus	opuntia	pore	sesame	sisal
	oats	onion	small sapote	spinach beet	sorghum	soybean	sweet potato	water melon
	pore	potato	sugar cane	tamarind				
	radish	soursop	tobacco					
	spinach beet	tomato						
SEMI-HOT	barley	cabbage	avocado	beet	agave	apple	aubergine	bean
	canary seed	celery	broccoli	castor bean	brown bean	carrot	cashew	celery
	lentil	lettuce	cauliflower	chayote	chick pea	chilli	coriander	cucumber
	mammey	pea	citrus	cocoa	fig	garlic	groundnut	jicama
	potato	radish	coffee	guava	linseed	maguey mezcal.	maguey tequilero	maiz
	rye	small sapote	jute	kenaf	mango	marron	melon	millet
	soursop	spinach	papaya	pomme gr.	oats	onion	opuntia (nopal)	parsley
	strawberry	wheat	quince	rice	pear	plum	pore	radish
			spinach beet	sugar cane	sesame	sisal	sorghum	soybean
			tamarind	tobacco	sweet potato	water melon		
TEMPERATE	asparagus	coriander	avocado	beet	apple	apricot	barley	beet
	parsley	strawberry	broccoli	caper	bean	brown bean	cabbage	canary seed
			cauliflower	chayote	carrot	cashew	castor bean	celery
			citrus	custard apple	cherry	chickpea	chilli	coriander
			guava	medlar	cucumber	fig	garlic	groundnut
			pomme gr.	rice	jicama	lentil	lettuce	linseed
			spinach beet	tamarind	maguey pulq.	maiz	marron	melon
			tomato	white sapote	millet	nut	oat	onion
					onion	opuntia	parsley	pea
					peach	pear	plum	pore
					potato	quince	radish	rye
					sarac.wheat	sorghum	soybean	spinach
					walnut	wheat		
SEMI-COLD	asparagus		beet	broccoli	apple	barley	bean	brown bean
			cauliflower	medlar	cabbage	canary seed	carrot	celery
			spinach beet	turnip	cherry	chick pea	chilli	coriander
					garlic	lentil	lettuce	linseed
					maguey pulq.	maiz	marron	millet
					oat	onion	opuntia (nopal)	parsley
					pea	pear	plum	pore
					potato	quince	radish	rye
					sarac.wheat	soybean	spinach	sweet potato
					wheat			

NOTE: Class 1, 2, 3 and 4 of Tables 4.15 and 4.16 represent decreasing degrees of water availablity: class 1 = no water deficiency; class 2 = water deficiency during the winter; class 3 = water deficiency all year round with good prospects for rainfed crops; class 4 = water deficiency all year round with limitated prospects for rainfed crops (see also the Köppen climates corresponding with these classes, indicated in Table 4.14). In arid and semi-arid regions irrigation will be needed to create the water availability conditions corresponding with classes 1, 2 and 3. In sub-humid conditions no class 4 water availability conditions have been considered in Table 4.16.

Table 4.17. Tolerance of crops to other limitations. Source: Quiñones et al., 1971, Table 18.

		Classes 1 - 2			Class 3		Class 4		Class 5	Class 6
EFFECTIVE SOIL DEPTH	apple	apricot	avocado	black pepper	abacá	artichoke	barley	bean	almond	agave
	cherry	citrus	cinnamon	clove	asparagus	aubergine	beet	broccoli	cashew	maguey mezcal.
	cocoa	coconut	coffee	cotton	banana	carrot	brown bean	cabbage	garlic	maguey pulq.
	cust.apple	date palm	fig	guava	castor bean	chayote[1]	canary seed	celery	guayule	maguey tequil.
	mammey	nut	nutmeg	olive	cherry	chilli	cauliflower	chick pea[1]	millet	
	peach	pear	pomme gr.	soursop	cucumber	grape	citrus	coriander	onion	
	tamarind	tea	walnut	white sapote	groundnut	jute	garlic	jicama	opuntia	
					kenaf	linseed	lettuce	maiz	pore	
					mango	melon	marron	medlar	sisal	
					papaya	potato	oat	pea	small sapote	
					safflower	sesame	pear	quince		
					sorghum	sugar cane	radish	rye		
					sweet potato	tobacco	rice	sarac.wheat		
					tomato	water melon	soybean	spinach		
							spinach beet	strawberry		
							sunflower	turnip		
							wheat			
SALINITY	abacá	agave (aloe)	almond	apple	asparagus	aubergine	beet	cotton		
	apricot	artichoke	avocado	banana	barley	bean	date palm	turnip		
	black pepper	broccoli[1]	cashew	castor bean	brown bean	cabbage				
	cauliflower	celery	cherry	chick pea[1]	canary seed	carrot				
	cinnamon	citrus	clove	cocoa	chilli	coconut				
	coffee	coriander	cucumber	custard apple	fig	garlic				
	groundnut	guava	guayule	jicama	grape	lettuce				
	jute[1]	kenaf	lentil	linseed	maiz	melon				
	maguey mezc.	maguey pulq.	maguey teq.	mammey	oat	olive				
	mango	medgar	millet	nut	onion	pore				
	nutmeg	opuntia	papaya	parsley	rice	rye				
	pea	peach	pear	pineapple	safflower	small sapote				
	plum	pomme gr.	potato	quince	sorghum	soybean				
	radish	sar.wheat	sesame	sisal	spinach	spinach beet				
	soursop	strawberry	sugar cane	tamarind	sunflower	sweet potato				
	tea	tobacco	vanilla	walnut	tomato	water melon				
	white sapote				wheat					

ALKALINITY	abacá	agave (aloe)	almond	apple	beet	date palm				
	apricot	artichoke	asparagus	aubergine	grape	oat				
	avocado	banana	barley	bean	safflower	tomato				
	black pepper	broccoli	brown bean	cabbage						
	canary seed	carrot	cashew	castor bean						
	cauliflower	celery	chayote	cherry						
	chick pea[1]	chilli	cinnamon	citrus						
	clove	cocoa	coconut	coffee						
	coriander	cotton	cucumber	custard apple						
	fig	garlic	groundnut	guava						
	guayule	jicama	jute[1]	kenaf						
	lentil	lettuce	linseed	maguey mezc.						
	maguey pulq.	maguey tequil.	mammey	mango						
	marron	medgar	melon	millet						
	nut	nutmeg	olive	onion						
	opuntia	papaya	parsley	pea						
	peach	pear	pineapple	plum						
	pomme gr.	pore	potato	quince						
	radish	rice	rye	sar.wheat						
	sesame	sisal	small sapote	sorghum						
	soursop	soybean	spinach	spinach beet						
	strawberry	sugar cane	sunflower	sweet potato						
	tamarind	tea	tobacco	turnip						
	vanilla	walnut	water mel.	wheat						
	white sapote									
ACIDITY	almond	artichoke	asparagus	avocado	apple	aubergine	apricot	cashew		abacá
	beet	carrot	celery	chayote[1]	barley	bean	cinnamon	citrus		agave (aloe)
	chick pea[1]	coriander	custard apple	date palm[1]	bl.pepper	broccoli	coconut	cotton		banana
	fig[1]	garlic	grape	groundnut	brown bean	cabbage	mango	nutmeg		cocoa
	guayule	jicama	jute	lentil[1]	canary seed	castor bean	peach	quince		coffee
	linseed[1]	maguey mezc.[1]	maguey pulq.[1]	maguey teq.[1]	cauliflower	cherry	rice	sw.potato		guava
	mammey	medgar	nut[1]	onion	chilli	clove				kenaf
	opuntia	olive[1]	parsley	pomme gr.[1]	cucumber	lettuce				pineapple
	pore	radish	safflower	small sapote	maiz	marron				sisal
	soursop	spinach	spinach beet	sunflower	melon	millet				sugar cane
	tamarind	walnut	white sapote		oat	papaya				tobacco
					pea	pear				
					plum	rye				
					sar.wheat	sesame				
					sorghum	soybean				
					strawberry	tomato				
					turnip	wheat				

NOTE: Classes 1,2,3,4,5,6 as defined in Table 4.14.

[1] *provisional classification, due to lack of information*

compound land utilization types should be very relevant for a country like Mexico, where many crops are grown in association.

Another observation is that more attention needs to be given to the other key attributes of the land utilization types, so as to ascertain more precisely the abilities of the farmers to manage, improve and conserve their land when growing the various crops. Present land use is an important key for further elaboration of the land utilization types. Unfortunately present land use is not a major concern of CETENAL. Their descriptions of present land use (legend of present land use and vegetation map) is extremely brief. For example, on CETENAL map sheet La Victoria F-14-A-22 the only differentiation made is: irrigation - permanent rainfed - shifting rainfed. The crops have been subdivided into annual, permanent and semi-permanent crops. Pastures have been separated into natural, cultivated and induced pastures.

Presentation of the results

The results of the Mexican land evaluation are represented on the map by the following symbols (example):

$$\underset{134}{4C}\ \begin{matrix}3\,S\\2\,T\end{matrix}\ /\ a\ l\ t\ /\underset{241}{2N}$$

4C	=	agrological capacity class 4, limitation C (effective soil depth)
3 S	=	agrological capacity class 3, limitation S (soil depth), less severe than C
2 T	=	agrological capacity class 2, limitation T (slope), less severe than S
a l t	=	improvement practices irrigation(a), leaching(l), stone removal(t)
2N	=	potential capacity class 2, limitation N (alkalinity)
134	=	code for combination of feasible crops for unimproved land
241	=	code for combination of feasible crops for improved land

To sum up: Figure 4.1 summarizes the procedure followed in the new CETENAL methodology. It may be concluded that this method has good possibilities for rapid improvement towards becoming a very informative land evaluation system for general and specific purposes if it is kept open for improvement and systematic incorporation of new information. More attention needs to be given to physical inputs and outputs (yields). Beside crops, other attributes of the land utilization types such as technology, capital and management level are also to be considered. The method represents an interesting stage in the search in Latin America for a specific purpose land evaluation system than can complement the USDA Land Capability System.

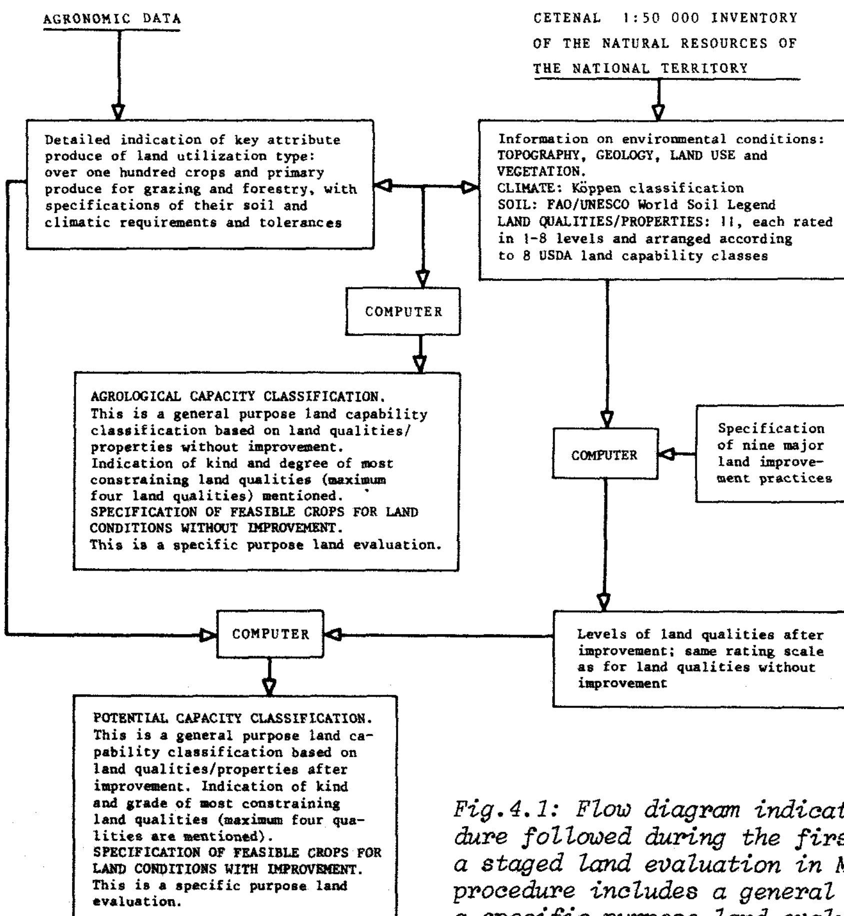


Fig.4.1: Flow diagram indicating procedure followed during the first stage of a staged land evaluation in Mexico. The procedure includes a general purpose & a specific purpose land evaluation.

4.3.4 Brazil: a system of physical land evaluation based on land qualities and land utilization types (at reconnaissance level)

Introduction

In Brazil, several institutions apply the USDA Land Capability System (e.g. Verdade *et al.*, 1974; INCRA, 1973, Quintiliano and Marques, 1971). But the Soil Survey and Conservation Service (SNLCS, EMBRAPA) of the Ministry of Agriculture has developed its own system of soil survey interpretation (Bennema, Beek and Camargo, 1964). The system was primarily designed to interpret reconnaissance-type soil surveys. It has provided many of the concepts and procedures of the FAO *Framework for land Evaluation* (Beek and Bennema, 1972; FAO, 1976). The first proposals for the use of land qualities, underlying this system, were formulated by J. Bennema, R. Costa de Lemos and J. Olmos when carrying out the reconnaissance soil survey of Sao Paulo State (Lemos *et al.*, 1960) This study even includes the land quality 'absence of risk of night frosts', so important for the coffee crop.

In the Brazilian system, land suitability classes *('classes de aptidão')* are determined for specific land utilization types, called 'management systems' in Brazil. The factors determining suitability are five land qualities (in Brazil named 'agricultural soil conditions') and the possibilities for their improvement. Each of the agricultural soil conditions is described in terms of degrees of limitation:

No limitation
Slight limitation
Moderate limitation
Strong limitation
Very strong limitation

Sometimes transitions between these degrees of limitation are used: slight to moderate, moderate to strong. When it is difficult to distinguish between two degrees of limitations, combinations have also been used: no + slight limitation, strong + very strong limitation.

The feasibility of improving the land qualities is rated as follows:

1. improvement easily feasible
2. improvement feasible

3a. improvement perhaps feasible

3b. improvement not feasible

Four land suitability classes have been distinguished:

class I	GOOD
class II	FAIR
class III	RESTRICTED
class IV	NOT SUITABLE

(Class IV has been subdivided into the subclasses IV A: Suitable for extensive grazing and IV B: Not suitable for extensive grazing).

Land Utilization Types

Land utilization types have a proper place in the Brazilian methodology. The following references are selected examples at different levels of soil survey and interpretation intensity:

Schematic soil inventory of North West, North East and Central Brazil, scale 1:5 000 000, total area 6 000 000 km^2 *(Camargo et al., 1975).*

Three separate soil suitability maps have been prepared for each of the following management systems:

Management System A (Routine management)

Farming practices in this system depend on traditional knowledge. No capital is used for farm or soil management and the level of technical knowledge is low. Draft power is usually manpower. If animals are used, only simple implements are available.

Management System B (Improved management)

Farming practices in this system reflect a reasonable level of technical knowledge. Some use is made of capital for maintenance and improvement of the agricultural soil conditions. Cultivation of crops mainly depends on hand labour and animal traction. If some power-operated machinery is used, this will be mainly for transport and processing, rather than for proper field operations.

Management System C (Advanced management)

Farming practices in this system depend upon a high level of technology. Intensive use is made of capital for maintenance and improvement of the agricultural soil conditions. Farming practices make full use of the results of modern agricultural research. Management practices in the field include the use of power-operated machinery.

On the land suitability map a distinction is also made between the suitability for short-cycle and long-cycle crops; e.g.:

- Class Ia: first class for short-cycle crops and long-cycle crops
- Class Ib: first class for long-cycle crops; second class for short-cycle crops
- Class Ic: first class for short-cycle crops; third class for long-cycle crops
- Class Id: first class for long-cycle crops; third class for short-cycle crops

The report does include a three-class climatic suitability classification for individual crops, based on the Köppen classifications of climate (Serra, 1960). Tables 4.19 and 4.20. illustrate the three management systems, A, B and C, on the distribution among economic components of crop production.

Interpretation of the exploratory soil survey of the cocoa belt of Bahia scale 1:1 000 000; total area 81 184 km^2 (Beek, Olmos et al., 1965).

Eight management systems were defined according to the following scheme:

Key attributes of land utilization types

	MANAGEMENT SYSTEM							
	I	II	III	IV	V	VI	VII	VIII
FARM POWER								
hand				+		+		+
animal		+	+					
tractor	+				+		+	
PRODUCE								
annual	+	+	+	+				
perennial					+	+		
cocoa							+	+
CAPITAL INTENSITY								
low			+	+		+		+
medium		+						
high	+				+		+	
TECHNICAL KNOWLEDGE								
low			+	+		+		
medium		+						+
high	+				+		+	

This is one of the few cases of low intensity soil survey interpretation for utilization by a specific crop (cocoa).

Monochrome soil suitability maps were prepared for each of the eight management systems, using hatching to distinguish between classes.

Reconnaissance soil survey and interpretation for agricultural uses of the soils of Iguatemi, Mato Grosso, scale 1:120 000; total area 22 230 km^2 (Ramalho Filho et al.,1970).

Here the land evaluation took into account two management systems only, 'primitive' and 'developed', both without irrigation. The definitions of these two systems correspond to the definitions of the management systems A and C of the previously mentioned schematic soil inventory, scale 1:5 000 000. Two separate monochrome soil suitability maps accompany the report. In some other reconnaissance-type soil survey interpretations, coloured suitability maps have also been included e.g. the reports of reconnaissance soil surveys and interpretations of the states of North East Brazil and of South Mato Grosso. All these interpretations only include management systems A and C and all make a distinction between the suitability for short-cycle and long-cycle (rainfed) crops.

Semi-detailed soil survey and interpretation of the areas owned by the Ministry of Agriculture in the Federal District of Brasilia, scale 1:25 000, total area 140 km2 (Alvarez Filho et al.,1970).

The soil survey interpretation was done separately for five management systems. The definitions of these five systems roughly correspond to the definitions of the management systems I, II, IV, V and VI applied in the interpretation of the exploratory soil survey of the cocoa belt of Bahia, already mentioned. No suitability maps were presented in the final report, only tables indicating the land suitability of each soil unit for each management system.

From these four examples it may be concluded that there is very little distinction in the detail of defining land utilization types at different intensities of survey. At reconnaissance and semi-detailed level, this detail could be increased. More attention should be paid to the suitability of the land for specific crops and their productivity. A recent example is the assessment of suitability for specific crops in North East Brazil (Klinger *et al.*, 1976) at scale 1:1 000 000.

At present the management systems are standard systems for the purpose of comparing all soil units on their physical suitability for the same purpose.

Land properties and land qualities

Soil survey interpretation in Brazil starts with the listing of land properties that may influence the land suitability classification. To this end the methodology includes a list of 23 selected properties with standards for their measurement and rating. Because of the difficulty of synthesizing these properties into the terms of land qualities, a short description of the role of the various properties (not necessarily all) in each of the land qualities is given in Appendix 2 of this report. In many interpretation systems soil depth is handled as an independent constraint rather than a component property of certain land qualities such as erosion susceptibility and available water. Therefore in the Brazilian methodology the role of soil depth in land evaluation has been treated separately.

The actual agricultural land conditions (or land qualities) are described as deviations from an 'ideal' soil, an approach which is similar to the description of limitations in the USDA Land Capability System. The ideal agricultural soil is defined as a soil that has a good natural fertility, no deficiency of water or oxygen, is not susceptible to erosion and has no impediments to the use of agricultural implements. Such a soil should have the widest range of possibilities for the highest organized forms of plant associations.

But there are special crops such as rice, cotton, eucalyptus, that have better or at least equally good possibilities on soils that differ from this ideal soil in one or more aspects. That is why the 'ideal' soil concept has been abandoned in more recent publications on land qualities and land evaluation (Beek and Bennema, 1971).

In Brazil the following agricultural soil conditions/limitations have been considered:

- (a) - deficiency of natural fertility, including the presence or absence of soluble salts
- (b) - deficiency of water (see Table 4.18)
- (c) - deficiency of oxygen (excess of water), including risk of overflow
- (d) - susceptibility to erosion
- (e) - impediments to the use of agricultural implements

A distinction is made between the 'ecological' conditions (a), (b) and (c) and the 'agricultural' conditions (d) and (e).

Each of these five conditions has been defined in terms of degrees of deviation from the ideal soil: zero, slight, moderate, strong, very strong (see Appendix 2).

Since their formulation in 1964, there have not been important changes in these definitions and the number of land qualities has not been increased. The main reason is probably that soil survey interpretation has mostly been concerned with reconnaissance-type studies for rather generalized types of land utilization: annual crops, or perennial crops in combination with only two or three levels of management.

Table 4.18 General relationship of climatic classification (Köppen) to predominant vegetation, length of dry season, general location and degrees of limitations due to deficiency of water

Climatic classification (Köppen)	Predominant vegetation	Average length of dry season	Gen. location within publication area	Degree of limitation for deficiency of water
Af	evergreen tropical forest, *campo*, *campo de várzea*	none: continuously hot and wet zone near equator	Amazonas	
Cfa	evergreen sub-tropical forest, grassland	none: always moist with few months in winter which are slightly drier	Southern part of Mato Grosso adjacent to Paraná	none
Am (Amw')	semi-evergreen tropical forest, *campo* (locally *campo cerrado* in Amapá)	short: 0-3 months	Amazon Region (greater part)	slight
	semi-evergreen tropical forest with *babaçu* palms			moderate (range to slight limitation)
Aw (Aw')	semi-deciduous tropical forest, *campo cerrado*, semi-deciduous tropical forest with *babaçu* palms, semi-evergreen tropical forest (Roraima), *campo*	moderately long 3 to 7 months	Central Brazil	
Cw (Cws, Cwbi)	*campo*, *campo cerrado*, deciduous forest (and transitions)	moderately long 3 to 7 months	Central Brazil above an altitude of 1000 m	moderate
Bswh' (BSw"h')	*caatinga* (equivalent of *mesquite* or deciduous low spiny shrubs and its transition to deciduous forest)	long: more than 7 months	Northeast Brazil	severe

Source: Camargo et al., 1975, p.470

Table 4.19 Model illustrating effect of three levels of technology on the distribution among economic components of crop production, expressed in dollars, per hectare of cultivated crops

Economic components of crop production	MODEL A Traditional hoe agriculture	B Hoe agriculture with hybrids & fertilizer	C Mechanized agriculture with hybrids & fertil.
		US$/ha	
Market value of crop produced	121.00	185.00	205.00
Fixed annual capital outlay			
cost of labour at survival-level subsistence	50.00	50.00	2.00
operational outlay costs (implements & equipment, amortization & maintenance, fuel, fertilizer, seed, marketing)	39.00	90.00	124.00
sum of fixed capital outlay	89.00	140.00	126.00
Surplus for optional distribution among interest, rent, debt, retirement, improvements, management, profit & negotiable segment of labor costs	32.00	45.00	79.00
Surplus item expressed as % of sum of annual fixed outlay	36%	32%	62%

NOTE: 1960 prices, 1US$ = 250 cruzeiros

Source: Haynes in AIAESD, 1960 (cited in: Camargo et al., 1975, p.503)

Table 4.20 Model illustrating effect of three levels of technology on the distribution among economic components of crop production, expressed in dollars, per worker

Economic components of crop production	MODEL: A Traditional hoe agriculture	B Hoe agriculture with hybrids & fertilizer	C Mechanized agriculture with hybrids & fertil.
	US$/worker		
Market value of crop produced	145.00	222.00	8 200.00
Fixed annual capital outlay			
labour cost at survival-level subsistence	60.00	60.00	60.00
operational outlay costs	46.00	108.00	4 940.00
sum of fixed capital outlay	108.00	168.00	5 000.00
Surplus for optional distribution among interest, rent, debt, retirement, improvements, management, profit & negotiable segment of labor costs	39.00	54.00	3 200.00
Cultivated hectares per worker	1.2 ha	1.2 ha	40.0 ha
Item of fixed segment of labour cost expressed in % of sum of annual investment cost	57%	36%	1%

NOTE: 1960 prices, 1US$ = 250 cruzeiros

Source: Haynes in AIAESD, 1960 (cited in: Camargo et al., 1975, p.509)

Land Improvement

As already mentioned, three classes of feasibility for improvement are used:

1. easily feasible with restricted input of capital and technical knowledge

2. feasible, but with considerable input of capital or technical knowledge (but still within the reach of economic possibilities)

3a. perhaps feasible after thorough investigations and/or large-scale improvement projects, beyond the scope of the majority of individual farmers

3b. not feasible

The land utilization type (management system) determines which land improvements are pertinent, while the soil (mapping) unit determines what the effect of these improvements will be.

In the schematic soil inventory of North, North West, North East and Central Brazil (Camargo *et al.*, 1975) no land improvement was considered in relation to management system A (routine management). For management systems B (improved management) and C (advanced management) the soil units were combined in so-called 'feasibility of improvement groups', according to:

(a) the degree of limitation before improvement
(b) the degree of limitation after improvement
(c) the suitability class of these soil units after improvement

For example the following grouping of soil units was made in connection with the limitation 'deficiency of natural fertility' and improvement to be made within management system B:

Group 1: soils with a slight to moderate limitation under natural conditions and no limitation after improvement. As far as soil fertility is concerned, class I land for short- and long-cycle crops after land improvement;

e.g. Eutrophic Non Calcic Brown soils.

Group 2: Soils with a slight to moderate limitation under natural conditions and no limitation after improvement. As far as soil fertility is concerned, class I land for short- and long-cycle crops after land improvement;

e.g. Eutrophic Latosol Roxo.

Group 3: soils with a slight to moderate or moderate limitation under natural conditions and a slight limitation after improvement (note: management system B can only afford modest amounts of fertilizers). As far as soil fertility is concerned, class II land for short- and long-cycle crops after land improvement;

e.g. Dystrophic Yellow Latosols, medium and heavy texture.

Group 4: soils with a strong limitation under natural conditions and a moderate limitation after improvement. As far as soil fertility is concerned, class III land for short- and long-cycle crops;

e.g. Undifferentiated Concretionary Soils of the Tropics.

Similar groupings of soils have been presented in connection with the other agricultural land conditions, for management systems B and C.

Land suitability classes and presentation of results

The most important single criterion for land suitability is the expected yield. Another important criterion is the ease and level of input needed for land improvement. Sustained production and erosion control are necessary conditions for the land utilization types that use physical inputs for land improvement. But a decrease in productivity and some erosion losses are considered inevitable in the traditional, low input type of land utilization in view of the prevailing management practices. Therefore separate definitions of land suitability classes have been presented for different management systems. Table 4.21A presents the definitions of land suitability classes for the three management systems A, B and C formulated in the schematic soil inventory of North, North West, North East and Central Brazil (Camargo *et al.*, 1975).

Fig. 4.2 is an example of presenting the results of land suitability classification, carried out by the Brazilian Soil Survey and Conservation Service along the Trans Amazon highway for purposes of identifying suitable areas for colonization by the National Institute for Colonization and Agrarian Reform (INCRA). Because of the predominance of the limitation 'soil fertility' and the problems involved in fertilizer use, a distinction has been made between land utilization with fertilizers and land utilization without fertilizers. A distinction has also been made between short-cycle crops, long-cycle crops and pastures (published in: Beek, Sombroek and Van Wambeke, Eds., 1972)[1].

In addition to such diagrams, maps and tables are the most common means of presenting the results of land suitability classification. Table 4.21B summarizes the results of the schematic soil inventory of North, North West, North East and Central Brazil (Camargo *et al.*, 1975).

To date, the Brazilian Soil Survey and Conservation Service has published separate land suitability maps for each management system. The advantage of clear presentation is, however, offset by the disadvantage of the cost involved in printing all these separate maps. For that reason the RADAMBRASIL Project, which uses the same land evaluation

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[1] *Goodland and Irwin (1974) present an interesting and controversial discussion of the environmental impact of the highway construction programme in the Amazon Basin.*

Table 21A: Definitions of land suitability classes in Brazil (reconnaissance level).
Source: Camargo et al., 1975

	MANAGEMENT SYSTEM A ROUTINE	MANAGEMENT SYSTEM B IIMPROVED	MANAGEMENT SYSTEM C ADVANCED
CLASS I GOOD	The soil conditions present no or slight limitations to a great number of climatically adapted crops. Good yields can be expected during a period of approx. 20 years, during which the yields will decrease only gradually.	The soil conditions present no or slight limitations to the sustained production of a great number of climatically adapted crops. Good yields can be obtained and maintained with relatively few management problems.	The soil conditions present no or slight limitations to the sustained production of a great number of climatically adapted crops. Good yields may be expected, but their maintenance may be somewhat affected by certain limitations which in this management system can only partly be removed.
CLASS II FAIR	The soil conditions present moderate limitations to a great number of climatically adapted crops. Good yields may be expected during the first ten years, after which the yields will decrease rapidly to medium yields for the next ten years.	The soil conditions present moderate limitations to a great number of climatically adapted crops. Good yields can be obtained in most years, but the number of alternative crops, the possibility of sustained production and the selection of management practices are restricted by one or more limitations which cannot wholly be removed.	The soil conditions present moderate limitations to the sustained production of a great number of climatically adapted crops. Good yields may be expected in most years, but the number of alternative crops, the maintenance of the productivity and the selection of management practices will be restricted by one or more limitations that cannot be removed.
CLASS III RESTRICTED	The soil conditions present strong limitations to a great number of climatically adapted crops. Medium yields may be expected during the first few years, after that yields will decrease rapidly to a low level within a period of ten years.	The soil conditions present strong limitations to the sustained production of a great number of climatically adapted crops. The yields are seriously reduced and the number of alternative crops is very much restricted by one or more limitations which cannot be removed.	The soil conditions present strong limitations to the sustained production of a great number of climatically adapted crops. The yields are seriously reduced and the number of alternative crops is very limited due to one or more limitations which cannot be removed.
CLASS IV NOT SUITABLE	The soil conditions present very strong limitations to a great number of climatically adapted crops. Low to very low yields may be expected even during the first years of use. Crops will not develop or it will not be feasible to plant them.	The soil conditions present very strong limitations to a great number of climatically adapted crops. Sustained production is not considered economically feasible, due to one or more limitations which cannot be removed. Only a few special crops may be adapted to such conditions, in combination with special management practices.	The soil conditions present very strong limitations to a great number of climatically adapted crops. Sustained production is not considered economically feasible, due to one or more limitations which cannot be removed.

Table 4.21b Approximate area and proportionate extent of suitability classes and subdivisions[1] in the delineations on the interpretative maps for the three management systems

Map symbols of suitability classes on interpretive maps	MANAGEMENT SYSTEM A Area (km^2)	Prop.extent (%)	B Area (km^2)	Prop.extent (%)	C Area (km^2)	Prop.extent (%)
Class I						
Ia	12 500	0.21	27 800	0.46	197 400	3.29
Ib	21 900	0.36	22 400	0.37	1 317 700	21.94
Ic	66 800	1.11	44 100	0.73	44 100	0.73
Id	-	-	-	-	333 800	5.55
TOTALS	101 200	1.68	94 300	1.56	1 893 000	31.51
Class II						
IIa	27 800	0.46	2 170 100	36.12	367 400	5.11
IIb	37 700	0.63	86 800	1,44	494 800	8.23
IIc	-	-	938 200	15.61	288 700	4.80
IId	-	-	-	-	938 200	15.61
TOTALS	65 500	1.09	3 195 100	53.17	2 089 100	34.75
Class III						
IIIa	3 528 200	58.72	266 200	4.43	256 904	4.28
IIIb	48 800	0.81	73 000	1.22	34 300	0.57
IIIc	-	-	-	-	5 200	0.09
TOTALS	3 577 000	59.53	339 200	5.65	296 404	4.94
Class IV	2 265 208	37.70	2 380 308	39.62	1 730 404	28.80
TOTALS	2 265 208	37.70	2 380 308	39.62	1 730 404	28.80
GRAND TOTALS	6 008 908	100.00	6 008 908	100.00	6 008 908	100.00

Source: Camargo et al. 1975, p.535

1 The meaning of the subdivisions is:

class	Ia	Ib	Ic	Id	IIa	IIb	IIc	IId	IIIa	IIIb	IIIc	IV
short cycle crops	I	II	I	III	II	II	III	IV	III	III	IV	IV
long cycle crops	I	I	III	I	II	III	II	II	III	IV	III	IV

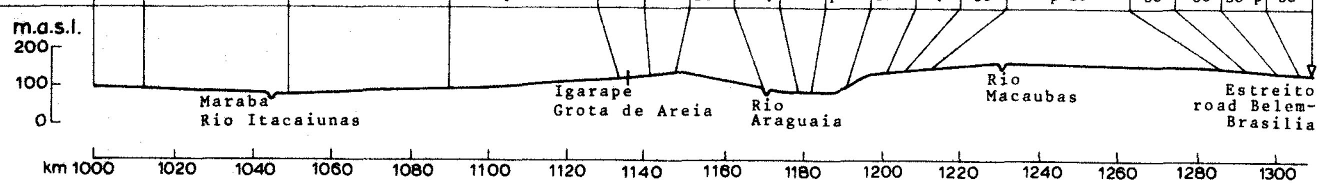
Fig.4.2 Diagrammetric presentation of land suitability along the Trans Amazon Highway, km 1000 to km 1310 Estreito (km 0: Itaituba)

WORKING GROUP ON EVALUATION AND MANAGEMENT OF SOILS IN THE AMAZON REGION

REGIONAL PROJECT FAO / UNDP RLA 70/457

SUITABILITY COLONIZATION INCRA — WITHOUT FERTILIZERS	III	IIIP IVCL	IIIP IVCL	IV	III	IV	III	III	IV
SUITABILITY COLONIZATION INCRA — WITH FERTILIZERS	IP IICL	IIIP IVCL	IIIP IVCL	IV	IV	IV	IICP IIIL	IC IIP IIIL	IV
VEGETATION		ssv-sc		ssv-sc			sc	sc	c
SOILS	LV 2 PVL 2 PVP 4	PVP 4 H 1	PVP 4 C 2	AQ 4	PV 4	AQ4 PV5	PV 6 PV 7 PV 5 TR 6 B 2	LA3	AQ 8
TOPOGRAPHY	o	so-o-p	so	p-so	so	so	so-o	so-p	so

SUITABILITY COLONIZATION INCRA — WITHOUT FERTILIZERS	IV	IC IIP IIIL	IV	IC IIP IIIL	IV	IIC IIIP IVL	IV	IIC IIIP IVL	IICP IIIL
SUITABILITY COLONIZATION INCRA — WITH FERTILIZERS	IV	IC IIP IIIL	IV	IC IIP IIIL	IV	IIIC IIIP IV L	IV	IIIC IIIP IV L	IC IIP IIIL
VEGETATION	c sc	sc	c cd	sc	c sc	cd	c sc	cd c	sc
SOILS	AQ 6 AQ 1	TR 5 B 3	AQ 7	TR 5 B 3	AQ 7 LE	L 1 V 1 B 3	AQ 7 AQ 5	V 2 L 1	LRE3
TOPOGRAPHY	p-so	so-o	p	so	p-so	so	so	so-p	so



LAND SUITABILITY CLASSES	TYPES OF CROPS
I Good II Fair III Marginal IV Not suitable	C Short cycle crops L Long cycle crops P Pastures

IC IIP IIIL	Example good for short cycle crops, fair for pastures, marginal for long cycle crops

P H A S E S			
VEGETATION		TOPOGRAPHY	
ssv	equatorial semi-evergreen	p	level (0-3%)
sc	equatorial semi-deciduous	so	gently undulating (3-8%)
cd	deciduous	o	undulating (8-20%)
c	cerrado (savannah)	fo	strongly undulating (20-40%)

Source: *Beek, Sombroek and van Wambeke, Eds. 1972*
Based on data provided by the Soil Survey and Conservation Service, EMBRAPA, Rio de Janeiro, Brazil

methodology for evaluating the natural resources of the Amazon Basin at 1:1 000 000 scale based on side-looking radar images and other remote sensing techniques has attempted to combine the two land suitability classifications for traditional and advanced technology into one land suitability map. Unfortunately the resulting map is rather confusing (PROJETO RADAMBRASIL, first 11 volumes).

To meet this problem, it was suggested that a multi-purpose land suitability map to serve agricultural planning at national, regional and State level should be prepared (Beek, 1975).

The land utilization types to be included in this map are:

A - crops (short- and long-cycle) with advanced management techniques
B - crops (short- and long-cycle) with improved management techniques
C - crops (short- and long-cycle) with traditional management techniques
P - intensive grazing on planted pastures
N - extensive grazing on natural pastures
S - silviculture
X - conservation of flora and fauna.

A six-group system has been proposed in which suitability group I is suitable for the greatest number of land utilization types: this number decreases with each lower group, group VI only being suitable for the conservation of flora and fauna. This approach is similar to that of the USDA Land Capability System, with the distinction that in Brazil three levels of management have been considered for crop cultivation and two levels of management for grazing. At the class level letter symbols have been used to indicate the suitability for each separate land utilization type: for instance: A-first class for land utilization type A; a - second class for land utilization type A; (a) - third class for land utilization type A. Tables 4.22A/B present the legend proposed for the multi-purpose land suitability map for broad agricultural planning purposes.

Table 4.22a Land suitability groups

GROUP I	Land with a good suitability for short-cycle crops, at least at one level of management; suitable for most less intensive types of land utilization
GROUP II	Land with a fair suitability for short-cycle crops, at least at one level of management; suitable for most less intensive types of land utilization
GROUP III	Land with a restricted suitability for short-cycle crops at least at one level of management; suitable for most less intensive types of land utilization
GROUP IV	Land suitable for planted pastures with a transitional level of management (incl.25-50 kg fertilizer nutrient/ha) and possibly for some less intensive uses (silviculture or extensive grazing)
GROUP V	Land suitable for extensive grazing on natural pastures with a traditional (low) level of management and/or for silviculture with a transitional level of management (including the application of small amounts of fertilizers)
GROUP VI	Land unsuitable for crops, grazing or forestry at any level of management, only suitable for preservation and conservation of flora and fauna (may include several productive types of utilization of the natural flora and fauna)

Source: Adapted from: Ramalho Filho, Guedes and Beek, 1977

Table 4.22b A multi-purpose land suitability classification

Land suitability group & subgroup	Land suitability class						
	SHORT CYCLE CROPS			PASTURES		SILVICULTURE	PRESERVATION & CONSERVATION OF FAUNA AND FLORA
	management level			management level		manag. level	
	traditional	transitional	advanced	planted trans.	natural trad.[1]	transitional	
I ABC	good	good	good	+	+	+	+
I AB	good	good	not suit.	+	+	+	+
I (a)Bc	restricted	good	fair	+	+	+	+
I (a)bC	restricted	fair	good	+	+	+	+
II abc	fair	fair	fair	+	+	+	+
II ab(c)	fair	fair	restr.	+	+	+	+
II bc	not suit.	fair	fair	+	+	+	+
II a	fair	not suit.	not suit.	+	+	+	+
II (b)c	not suit.	restr.	fair	+	+	+	+
III (abc)	restricted	restricted	restr.	+	+	+	+
III (ab)	restricted	restricted	not suit.	+	+	+	+
III (bc)	not suit.	restricted	restr.	+	+	+	+
III (a)	restricted	not suit.	not suit.	+	+	+	+
III (b)	not suit.	restricted	not suit.	+	+	+	+
III (c)	not suit.	not suit.	restr.	+	+	+	+
IV P	not suit.	not suit.	not suit.	good	+	+	+
IV p	not suit.	not suit.	not suit.	fair	+	+	+
IV (p)	not suit.	not suit.	not suit.	restricted	+	+	+
V Sn	not suit.	not suit.	not suit.	not suit.	fair	good	+
V S(n)	not suit.	not suit.	not suit.	not suit.	restricted	good	+
V S	not suit.	not suit.	not suit.	not suit.	not suitable	good	+
V n	not suit.	not suit.	not suit.	not suit.	fair	not suit.	+
V sn	not suit.	not suit.	not suit.	not suit.	fair	fair	+
V (s)n	not suit.	not suit.	not suit.	not suit.	fair	restricted	+
V s(n)	not suit.	not suit.	not suit.	not suit.	fair	not suit.	+
V (n)	not suit.	not suit.	not suit.	not suit.	restricted	not suit.	+
VI	not suit.	not suit.	not suit.	not suit.	not suitable	not suit.	+

[1] *If the natural vegetation permits grazing*

Source: Adapted from Ramalho Filho, Guedes and Beek, 1977

By using different types of overprints multi-purpose land suitability maps can provide additional information on the areas where crops with special land requirements can be grown (e.g. cashew and perennial cotton in North East Brazil), on land that is suitable for producing two crops per year, land that is suitable for long-cycle crops only, land that is not suitable for long-cycle crops but suitable for short-cycle crops, land that is not suitable for any other crops except inundated rice, land where irrigation is foreseen or has already been installed.

A multi-purpose land suitability map has some advantages over sets of single-purpose suitability maps:

- It shows the development perspective for all land-use alternatives under consideration. The suitabilities for land utilization types with different levels of management can be compared without having to superimpose the single-purpose map. This will be useful for long-term perspective planning

- It shows the range of development alternatives for each mapping unit. This will be useful for land use planning, and also for a shorter time perspective

- Area calculations can be made distinguishing between areas of different flexibility in the selection of land use alternatives and different development perspectives: some areas are only suitable for one level of technology, low, medium or high; other land units may be suitable for step-wise development, presenting possibilities for traditional as well as for transitional and advanced technologies, while there may be still other land units that have a certain ceiling for development, being suitable only for traditional and transitional levels of management. Such information is pertinent for long-term sequential development planning. Area calculations supporting this type of planning are difficult to make on the strength of single-purpose maps.

Conversion tables

The most interesting aspect of Brazilian land evaluation methodology is the way that has been found to overcome the problem of relating the land qualities and the feasibility of their improvement to the land suitability classes.

To do this a conversion table is constructed. A conversion table is site specific, because of the climatic variation between different sites, which has not been fully incorporated in the five land qualities under consideration: the available water has been included, but not the other features of the climate such as temperature and radiation. Tables 4.23/25 are examples of conversion tables that have been used to interpret the schematic soil inventory of North, North West, North East and Central Brazil (Camargo et al., 1975). Of course separate conversion tables are prepared for each land utilization type.

But when preparing a multi-purpose land suitability map a multi-purpose conversion table can also be constructed (Beek, 1975d; this proposal includes three multi-purpose conversion tables for the (humid) tropics, the (humid) sub-tropics, and the semi-arid zones).

Conversion tables in Brazil do not consider the cumulative effect of different limiting land qualities. The land suitability class is determined by the most limiting land quality after improvement (if improvement is feasible). This problem still needs to be solved.

A first step in the right direction was made in the land evaluation for livestock development on Marajó Island in the Amazon Estuary (IDESP, 1974) which considers the cumulative effect of excess water of Ground Water Laterites (Plinthaquults) in one season and water deficiency during another season.

Conversion tables give an instantaneous picture of the state of the art of land evaluation in a specific location and in connection with a specific use. Their reliability will depend to a great extent on the availability of site-specific research-tested information. In areas where reconnaissance type land evaluations have to be carried out, this type of information is often very hard to obtain and transfer of knowledge through correlation and analogy with better known areas is therefore important. In Brazil the use of land qualities has been an important means for permitting this transfer of knowledge. Also, the fact that great attention is given to systematic soil classification and soil correlation has been very useful for systematic soil survey interpretation. However it must be admitted that there is now a great need in Brazil for conversion tables that permit land suitability classification for specific crops at defined levels of management, with due attention to the climatic parameters, and to soil conservation and to productivity.

Conclusion: the soil survey interpretation methodology developed in Brazil, and proved to be so useful for regional planning, (e.g. Pereira *et al.*, 1974) will need to be further developed to support more specific types of agricultural planning and development at the local and farm level. This will require more participation from agronomists who know the land requirements of the crops, and of agro-meteorologists who are able to supply more detailed information about the climatic variation to complement the excellent soil information collected and published by the Soil Survey and Conservation Service. Only then will the Brazilian methodology reach the full status of a physical specific purpose land evaluation method, as described in Section 4.2.1. The method as it now stands is intermediate between general purpose and specific purpose physical land evaluation, giving satisfactory results in reconnaissance type land evaluation but too superficial results at more detailed levels.

Table 4.23 Management system A (primitive)

Conversion table for assigning soils to suitability classes for short-cycle and long-cycle crops, based on degrees of limitations under natural soil conditions, for five major aspects of the agricultural soil conditions[1]

Broad suitability classes for short-cycle and long-cycle crops	Estimate of degrees of limitation				
	fertility deficiency	water deficiency	excess water	erosion susceptibility[2]	impediments to mechanization[2]
Short cycle crops					
I - good	no limitation/ slight	no limitation slight slight/moderate	no limitation no limit./slight slight	no limitation slight slight/moderate	no limitation slight moderate
II - fair	slight slight/moderate	moderate	moderate	moderate/strong	strong
III - restricted	moderate	strong	strong	strong	very strong
IV - not suitable	strong very strong	strong	very strong	very strong	-

long cycle crops

I - good	no limit./slight	no limitation slight	no limitation no limit./slight	no limitation slight slight/moderate moderate moderate/strong	no limitation slight moderate
II - fair	slight slight/moderate	slight/moderate	slight	strong	strong
III - restricted	moderate	moderate	moderate	strong	very strong
IV - not suitable	strong very strong	strong	strong very strong	very strong	-

[1] *It is assumed that the limitations cannot be moderated in any manner under the A (primitive) system of management. The overall suitability class for a specific kind of soil is assigned on the basis of the most limiting class indicated for any of the five major aspects influencing use. See introduction to this table for example of this procedure.*

[2] *The aspect of susceptibility to erosion is not too significant and the aspect of use for agricultural machinery is not significant at this A (primitive) level of management. However, by combining the assigned limitations as shown in the table, it is possible to reflect some erosion hazards in hand cultivation, and some problems in the use of manpower in contrast to tractor powered equipment; thus providing some management information for these two aspects.*

Source: Camargo et al., 1975

Table 4.24 Management system B (semi-developed, without irrigation)

Conversion table for assigning soils to suitability classes for short-cycle and long-cycle crops. Based upon the ease or difficulty of removing, moderating or controlling the assigned degrees of limitations under natural conditions, through the effects of the levels of management.[1] (The practices necessary to improve the limitations must be maintained.)

Suitability classes for short-cycle and long-cycle crops	Estimate of degrees of limitation after possible improvement[2] for				
	fertility deficiency	water deficiency	excess water	erosion susceptibility	impediments to mechanization[3]
Short cycle crops					
I - good	none slight slight/ *none* (none to slight - 1) *none* (slight/moder. and moderate - 2)	none slight slight/	none *none* (slight - 1)	none *none* (slight and slight/moderate - 1)	none to slight
II - fair	slight *slight* (slight/moder. and moderate - 3)	moderate	slight *slight* (mod.2)	slight *slight* (moderate and mod./strong-2)	moderate
III - restricted	moderate *moderate* (strong - 4)	strong	moderate *moderate* (strong - 3)	moderate *moderate* (mod./strong and strong - 3)	moderate
IV - not suitable	strong very strong	strong	strong very strong	strong very strong	strong very strong

Long cycle crops

I - good	*none* (none to slight - 1) *none* (slight/ mod. and mod. - 2)	none slight	none *none* (slight-1)	none *none* (slight and slight/mod. - 1) slight *slight* (moderate and mod./strong-2)	none slight
II - fair	slight *slight* (slight/ mod. and mod.-2)	slight/moder.	*slight* (mod.-2)	*moderate* (mod./ strong and strong - 2)	moderate
III - restricted	moderate *moderate* (strong-4)	moderate	slight	moderate	strong
IV - not suitable	strong very strong	strong	*moderate* (strong - 3) strong very strong	strong very strong	very strong

[1] The overall suitability class for a specific kind of soil is assigned on the basis of the most limiting class indicated for any of the five major aspects influencing use. See introduction to this table for example of this procedure.

[2] The adjective ratings - none, slight, moderate, severe, very severe - indicate the degree of limitation either under natural conditions or after improvement. Where they are used alone the limitation is based upon the natural conditions, and improvement is not considered feasible under this management level. Where they are followed by adjective ratings and numbers in parenthesis, the limitation is indicated both after improvement and under natural conditions. For example, a rating of *None* (moderate-2) means that after improvement there are no limitations in use, but under natural conditions there are moderate limitations. The arabic numbers refer to a group of soils listed in the text with this improvement possibility.

[3] The aspect of use for agricultural machinery is not too significant at this B-level of management. However, by combining the assigned limitations as shown in the table, it is possible to reflect cultivation problems in the use of animal powered equipment in contrast to tractor powered equipment; thus providing some management information for this aspect.

Source: Camargo et al., 1975

Table 4.25 Management system C (advanced, without irrigation)

Conversion table for assigning soils to suitability classes for short-cycle and long-cycle crops. Based upon the ease or difficulty of removing, moderating or controlling the assigned degrees of limitations under natural conditions, through the effects of levels of management.[1] (The practices necessary to improve the limitations must be maintained.)

Broad suitability classes for short-cycle and long-cycle crops	Estimate of degrees of limitation after feasible improvement[2]				
	fertility deficiency	water deficiency	excess water	erosion susceptibility	impediments to mechanization
Short cycle crops					
I - good	*none* (none to slight - 1) *none* (slight/mod. and moderate - 2) *none* (strong - 3)	none slight slight/moderate	none *none* (slight - 1)	none *none* (slight and slight/mod. - 1) *none* (moderate - 2 and mod./strong)	none
II - fair	slight *slight* (mod. - 4) *slight* (strong-5)	moderate	slight *slight* (mod. - 2)	*slight* (mod./ strong and strong - 3)	slight
III - restricted	moderate	moderate	moderate *moderate* (strong - 3)	slight	moderate
IV - not suitable	moderate strong very strong	strong	strong very strong	moderate strong very strong	strong very strong

Long cycle crops

I - good	*none* (none to slight - 1) *none* (slight/ and mod. - 2) *none* (strong - 3)	none slight	none *none* (slight - 1)	none *none* (slight and slight/mod. - 1) *none* (mod. mod./strong - 2) *none* (mod./ strong and strong - 3)	none slight
II - fair	slight . *slight* (mod. -4) *slight* (mod. - 5)	slight/mod.	*slight* (mod. - - 2)	slight	moderate
III - restricted	moderate	moderate	slight	moderate	strong
IV - not suitable	moderate strong very strong	strong	moderate *moderate* (strong - 3) strong very strong	strong very strong	very strong

[1] The overall suitability class for a specific kind of soil is assigned on the basis of the most limiting class indicated for any of the five major aspects influencing use. See introduction to this table for example of this procedure.

[2] The adjective ratings - none, slight, moderate, severe, very severe - indicate the degree of limitation either under natural conditions or after improvement. Where they are used alone the limitation is based upon the natural conditions, and improvement is not considered feasible under this management level. Where they are followed by adjective ratings and numbers in parenthesis, the limitation is indicated after improvement and under natural conditions. For example: a rating of *None* (moderate-2) means that after improvement there are no limitations in use, but under natural conditions there are moderate limitations. The arabic numbers refer to a group of soils listed in the text with this improvement possibility.

Source: Camargo et al., 1975

4.3.5 Chile: an example of integral land evaluation with staged procedure

After the very damaging earthquakes of May 1960, the Organization of American States (OAS) recommended a vast programme of reconstruction in the affected areas in Chile. This recommendation resulted in the largest integrated land resources survey project to that date, based on aerial photograph interpretation. It included the study of present land use, land ownership, geology and geomorphology, meteorology and climatology, hydrology, soils and soil limitations, forestry, irrigation and drainage systems, economic studies and land capability.

The results of this enormous study, which covered 120 000 km^2, should guide land reform taxation programmes, and irrigation and agricultural development.

The soil study distinguishes 350 different soils, classified in terms of series, types and phases. The main purpose of the soil study (and of the studies of other land attributes) was the rapid determination of the land capability (according to the USDA Land Capability System). Observation and measurement of soil properties and soil limitations included a predetermined set which are rated similarly for the entire country. Such a 'coordinate system' [1] of soil inventory (Van Wambeke, 1972) permits a rapid, broad picture but does not allow for precise soil classification nor for precise interpretation. The method chosen is indeed rapid: with the help of 1:20 000 aerial photographs and controlled photomosaics at the same scale (472 mosaics of 270 km^2 each) 16 soil scientists completed the field work for the 1:20 000 soil map in 16 calendar months. The coastal zone was surveyed at a smaller scale, 1:50 000. Field checking included 10-100 observations per mosaic, with an average of 25. This means that the average observation density was one per 1100 hectares, with a range of 1:270 ha to 1:2700 ha. 750 profiles belonging to 200 soil series were sampled and analysed in the laboratory. The scale at which the maps were published (1:20 000) suggests that the soil sampling was more detailed than it actually was. Broad planning at national

1 *See Section 4.3.1 for explanation.*

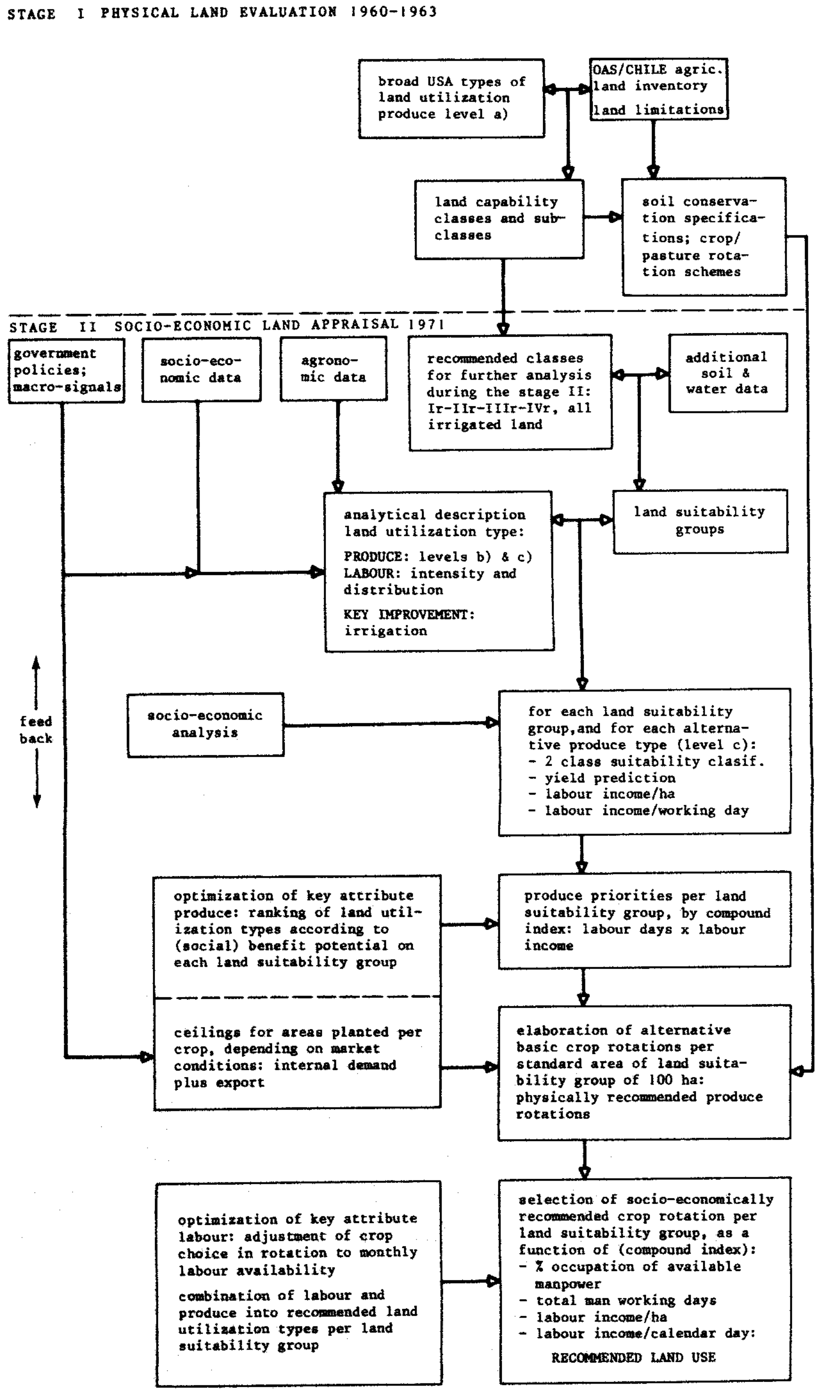


Fig.4.3: Staged land evaluation with 11-year time interval between stages. Chile 1960 - 1971.

and regional level may be served by such schematic study, but more detailed planning cannot be based entirely on its results. In The Netherlands a density of one observation per 5-6 hectares is not unusual for a 1:20 000 scale soil map (the variability of the soil properties in the survey area is important). For a reconnaissance soil survey in Portugal for purposes of irrigation and drainage planning, scale 1:25 000, an observation density of 1 per 12 hectares was recommended (Schulze and Beek, 1976).

It is interesting to analyse how the results of this OAS/CHILE Aero-photogrammetric Project were intended to be used for detailed land use planning in agrarian reform areas (IICA/CORA, 1971), particularly because this planning is a good example of stage II of a staged land evaluation procedure: socio-economic analysis (see Section 4.2.2). So far our discussions of land evaluation (in Venezuela, Nicaragua, Mexico and Brazil) have only been concerned with stage I: Physical analysis.

Figure 4.3 summarizes the proposed IICA/CORA method of land use planning for agrarian reform purposes. In this procedure the OAS/CHILE project, although implemented 10 years earlier, represents stage I of the staged integral land evaluation procedure. The IICA/CORA method is mainly concerned with stage II, socio-economic analysis. It is particularly interesting to note how the IICA/CORA method attempts to combine single land utilization types into compound land utilization types (crop rotations) with the aim of maximizing the use of labour and the labour income, taking into account the physical limitations of the land, the availability of labour, the prices of inputs and outputs and the market restrictions for certain products. The method is not sophisticated in its approach to data processing; it does not rely on linear programming, but on simple input-output studies and production functions. It is interesting for its strong reliance on the results of physical land evaluation.

Agronomic considerations during Stage II

a) *The role of the soil information*

The result of stage I, physical land evaluation, is a map of land capability classes and subclasses, USDA type, scale 1:200 000. For this classification US-type management practices have been assumed. The classes Ir. IIr, IIIr and IVr, which correspond with land that is already under irrigation, were selected by the IICA/CORA method for further socio-economic analysis because these are the classes that have been classified as being capable of growing agricultural crops. The US Capability System does not assess the capability of the land for the specific purpose of irrigated crop cultivation. Therefore capability classes I-IV do not necessarily correspond in that order with land capability for irrigated land use. Land evaluation for irrigated land use should require additional observation and measurement of such properties as infiltration rate, hydraulic conductivity in saturated and unsaturated zone, fluctuations of the groundwater tables, surface characteristics conditioning the flow of irrigation and drainage water, water quality and availability, etc. (USBR, 1953; FAO, 1976).

The IICA/CORA methodology foresees that the land capability information will be complemented by additional data, unfortunately to a very limited extent: four textural classes have been added and the availability of irrigation water is rated, distinguishing between a scarce and an abundant supply. Thus fourteen so called 'land suitability groups' have been established, to be handled as homogeneous land units for socio-economic analysis and land use planning; see Table 4.26.

Cross reference to the original information on soil series, types and phases, produced during stage I was only made when adding the textural phases. The other land properties/limitations are assumed to be sufficiently characterized by the land capability classes and subclasses. The justification for this rather superficial treatment of the data base has been the need for a rapid method of land evaluation, because of the urgency to implement the government's land reform policies. Oversimplification of the land resources data in socio-economic studies is more likely to occur when the physical land evaluation (stage I) exceeds its claim on the usefulness of its products for certain types of land use planning. Considering the low density of the observation network of the OAS/CHILE land inventory this seems to have been the case. Later more detailed soil surveys of parts of the Central Valley by the Chilean Soils Institute confirmed these reservations about the reliability of these soil resources maps (personal communications Mella, Culot, 1972).

Table 4.26 The fourteen land suitability groups

Group	Capability class	Texture	Availability irrigation water
A	Ir	medium	abundant
B	Ir	medium	scarce
C	IIr	medium to light	abundant
D	IIr	medium to light	scarce
E	IIr	medium to heavy	abundant
F	IIr	medium to heavy	scarce
G	IIIr	medium to light	abundant
H	IIIr	medium to light	scarce
I	IIIr	heavy	abundant
J	IIIr	heavy	scarce
K	IVr	medium to light	abundant
L	IVr	medium to light	scarce
M	IVr	heavy	abundant
N	IVr	heavy	scarce

Source: IICA/CORA, 1971

b) The role of the land utilization types

Stage II of an integral land evaluation procedure should scart with a close look at the type of land utilization assumed during stage I for making the land capability classification. But stage I has only been concerned with very generalized types of land utilization: (annual) agricultural crops, cultivated with US-type management techniques (e.g. mechanized) and well supplied with the necessary physical inputs for soil improvement and conservation. The IICA/CORA method is particularly interested in land utilization types that can meet the government criteria guiding all development planning:

- full employment
- maximization of labour productivity
- compatibility of projected supply of products with the policies of internal demand and export of agricultural products
- minimization of investments in indirectly productive infrastructure.

IICA/CORA aims to select crops and crop rotations that permit maximum labour absorption and the highest possible income for each land suitability group. To this end the very generalized land utilization type of stage I has been broken down into three so-called 'agronomic groups':

- *chacra* (intensive annual crops)
- cereals
- forage crops

Rotation schemes consist of different sequences of these three groups; each rotation scheme has its own labour, management and conservation requirements.

Each agronomic group has been further brok down into a number of specific crops:

LEVEL A	LEVEL B	LEVEL C
Generalized land utilization type	agronomic groups	specific crops
agricultural crops	*chacra*	maize, sunflower, melon, potato, beet, sugar beet, watermelon, tobacco, tomato
	cereals	rice, barley, wheat
	forage crops	alfalfa, oats, ryegrass, clover

The suitability of each 'land suitability group' is assessed for each of these crops (see Table 4.27). This is essentially a two-class specific purpose physical land evaluation: class I-suitable; class II-unsuitable.

Table 4.27 Recommended crops for each land suitability group A - N

Produce	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Maize	+	+	+	+	+	+	+	+	+	+	+	-	-	-
Sunflower	+	+	+	+	-	-	+	+	-	-	+	-	-	-
Melon	+	+	+	+	-	-	+	+	-	-	+	-	-	-
Potato	+	+	+	+	-	-	-	-	-	-	-	-	-	-
Beans	+	+	+	+	+	+	+	+	-	-	+	-	-	-
Beet	+	+	+	+	-	-	+	+	-	-	+	-	-	-
Sugar beet	+	+	+	-	-	-	+	-	-	-	+	-	-	-
Watermelon	+	+	+	+	-	-	+	+	-	-	+	-	-	-
Tobacco	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Tomato	+	+	+	-	-	-	+	-	-	-	+	-	-	-
Rice	-	-	-	-	-	-	-	-	+	-	-	-	+	-
Barley	+	+	+	+	+	+	+	+	-	+	+	+	-	+
Wheat	+	+	+	+	+	+	+	+	-	+	+	+	-	+
Dairy farming	+	+	+	+	+	+	+	-	-	-	-	-	-	-
Livestock fattening	-	-	-	-	-	-	+	+	+	+	+	+	+	+

Source: IICA/CORA, 1971, p.41

The same criticism that was made of the Nicaraguan example (Section 4.3.2) about mixing general purpose land evaluation (USDA-type land capability classification) with specific purpose land evaluation (land suitability classification for specific crops) could be made here. The IICA/CORA rating of land suitability for specific crops should have been prepared during stage 1. Considering the precision with which the present land use was studied and mapped during the OAS/CHILE agricultural land inventory (see Table 4.28), which is the legend of the present land use map, it is surprising that specific purpose land evaluation did not receive more attention during that project.

Table 4.28 Present land use classification in Chile. (Source: The OAS/Chile Aero-photogrammetric Project, 1964, p.66).

1	URBAN AREAS
1a	Urban and associated areas
1b	Government installations and other institutional land
2	HORTICULTURAL LANDS
2a	Commercial horticulture, irrigated
2b	Commercial horticulture, not irrigated
2c	Domestic horticulture, irrigated
2d	Domestic horticulture, not irrigated
3	LANDS WITH FRUIT ORCHARDS AND OTHER PERMANENT CROPS
3a	Fruit orchards, irrigated
3b	Fruit orchards, not irrigated
3c	Vineyards, irrigated
3d	Vineyards, not irrigated
3e	Trellised vineyards
3f	Multiple use with fruit orchards
4	LANDS WITH EXTENSIVE CULTIVATION
4a	Rotation of *chacra*-cereal-pasture, irrigated
4b	Rotation of *chacra*-cereal-pasture, not irrigated
4c	Rotation of cereal-pasture, irrigated
4d	Rotation of cereal-pasture, not irrigated
4e	Rotation of rice
4f	Principally *chacra*, irrigated
4g	Principally *chacra*, not irrigated
5	PERMANENT IMPROVED PASTURES
	(This category is not applicable in Chile.)
6	NATURAL PASTURES
6a	Pastures on semicleared land
6b	Pastures with or without brush, not cultivated
6c	Pastures with brush, pasture cover very sparse
6d	Pastures with brush, river floodplain
7	FOREST LANDS
7a	Natural forests
7b	Planted forests, irrigated
7c	Planted forests, not irrigated
7d	Cut forests, irrigated
7e	Cut forests, not irrigated
7f	Second growth
7g	Brush
8	WET LANDS
9	LANDS WITHOUT USE

More recent soil studies made by the Chilean Soil Institute do include land suitability ratings for specific crops. For example a checklist of land utilization types was published in the semi-detailed soil surveys of Maule Norte and Digua (Table 4.29). Each soil (mapping) unit was rated suitable/unsuitable for these types. The land utilization types/crops suitable are physically feasible options, similar to the crop lists prepared in Mexico with the new CETENAL methodology (Section 4.3.3). There is no mention of required inputs and/or expected outputs. In Chile the term 'agricultural soil suitability' is used for this kind of rating.

Table 4.29 Land utilization types applied for two class 'agricultural suitability' classification by the Chilean Soil Institute

1. All cultivated crops (*chacras*, cereals, pasture), deep rooting fruit trees, or vineyards
2. All cultivated crops (*chacras*, cereals, pastures), medium deep rooting crops, or vineyards
3. All cultivated crops (*chacras*, cereals, pastures), shallow rooting crops, or vineyards
4. All cultivated crops and deep rooting fruit trees
5. All cultivated crops and medium deep rooting fruit trees
6. All cultivated crops and shallow rooting fruit trees
7. All cultivated crops (mainly horticultural crops) and medium deep rooting fruit trees
8. All cultivated crops (mainly horticultural crops)
9. *Chacras*, cereals and deep rooting pastures
10. *Chacras*, cereals and medium deep rooting pastures
11. *Chacras*, cereals and shallow rooting pastures
12. *Chacras*, cereals and resistant pastures
13. Cereals, pastures and deep rooting fruit trees, or vineyards
14. Cereals, pastures and middle deep rooting fruit trees, or vineyards
15. Cereals, pastures and vineyards
16. Cereals or pastures
17. Cereals, shallow rooting pastures or vineyards
18. Cereals or shallow rooting pastures
19. Cereals (mainly rice) and pastures
20. Shallow rooting pastures
21. Natural pastures
22. Forestry
23. Wildlife and recreation

Source: Estudio Agrológico del Area Maule Norte (2a etapa, App.VI, 1969)

When examining Table 4.27 the question arises whether the variation of properties affecting the suitability for the crops mentioned within each land suitability group is really smaller than the variation in properties between these groups, at least between the groups now rated suitable and unsuitable. How far apart are, for instance, groups D and F in their suitability for growing sunflower, melon or watermelon, and how great is the variation in suitability for these crops within each of these two groups?

Productivity

To select the optimal crop rotation for each land suitability group the productivity of these groups when growing the various crops needs to be known. IICA/CORA correlates crop yield with land capability classes, by using standards established by the National Agronomic Institute La Platina. However, such a correlation is questionable, because the land capability classes defined in the OAS/CHILE report (see Table 4.30) are not explicit about crop yield. The USDA Land Capability System (Klingebiel and Montgomery, 1961) also recognizes that for a proper assessment of productivity and yield potential the soil (mapping) units not the land capability classes should be used as a base.

Correlating crop productivity with the various land capability classes introduces a subjective element in the socio-economic analysis of stage II which can seriously interfere with the accuracy of the conclusions on integral land evaluation.

Table 4.30 Definitions of the land capability classes I-IV in Chile

C L A S S I.

Soils in this class have very few limitations restricting their use. Agricultural land is considered suitable for a wide range of intensive cultivation, grazing, and forestry. The terrain is almost flat, and there is little or no erosion hazard. Soils are deep, generally well drained, and easy to work; they hold water well and respond positively to fertilizers. Soils in irrigated areas may be placed in this class if the limiting factor of aridity has been taken care of by the installation of permanent irrigation works. Land having slowly permeable subsoils is not included in this classification. Class I soils used for growing crops only require ordinary management practices to maintain productivity, both in terms of fertility and soil structure.

C L A S S II.

These soils have some limitations that reduce the selection of crops that can be grown or make moderate conservation practices necessary. These limitations may be due to the effects of (1) gentle slope (2) moderate susceptibility to wind or water erosion (3) shallow soils (4) somewhat unfavorable structure of the soil itself (5) slight or moderate salinity or sodium content, easily corrected (6) moderately limiting permanent wetness that can be corrected by drainage (7) occasional damaging overflow (8) minor climatic limitations on soil use and management. Land in this class requires special cultivation systems, soil conservation practices, water control devices, and careful tilling methods when used for certain crops. The combination of management practices varies from one locality to another, depending on climate, characteristics of the soil, and the cultivation system used.

C L A S S III.

Soils in this class have severe limitations that either reduce the selection of plants that can be grown or require special conservation practices, or both. These limitations restrict the amount and the choice of crops and may delay the growing time of the plants and postpone cultivation and harvesting. This can result from the following causes: (1) moderately steep slope (2) high susceptibility to wind or water erosion or to severe adverse effects of earlier erosion (3) frequent overflow, accompanied by some crop damage (4) very slow subsoil permeability (5) continuing wetness of the soil after drainage (6) shallow depths to bedrock, hardpan, or claypan that would limit the rooting zone and water storage (7) low moisture-holding capacity (8) low fertility, difficult to correct (9) moderate salinity or sodium content (10) moderate climatic limitations. When land in this category is cultivated, it requires drainage and a cultivation system that will maintain or improve the structure of the soil. For each Class III soil there are one or more alternative combinations of practices for improving its use, but the number of these alternatives is less than in the case of Class II.

C L A S S IV.

Soils in this class have very severe limitations that restrict the selection of plants that can be grown or require very careful management, or both. These soils can only be used for two or three of the common crops, and the yield is low in relation to inputs. Use for cultivated crops is limited as a result of the effects of one or more permanent conditions, such as (1) steep slopes (2) severe susceptibility to wind or water erosion (3) severe effects of earlier erosion (4) shallow soils (5) low moisture-holding capacity (6) Frequent overflows, accompanied by heavy crop damage (7) excessive wetness (8) severe salinity or sodium content (9) moderately adverse climate. Many soils in this category are suitable for occasional, but not regular, cultivation. Others are appropriate for fruit trees, ornamental trees, or shrubs. In subhumid and semiarid areas, soils in this class produce good yields in years of above average rainfall, low yields in years reporting normal precipitation, and very poor yields in dry years. Class IV land requires special treatments and practices to prevent soil blowing, to retain moisture, and to maintain soil productivity.

Source: The OAS/CHILE Aero-photogrammetric Project (1964,p.96-101)

Economic considerations during stage II

a) Labour: to know the labour available monthly for agriculture (man, animal, equipment) local statistics were consulted.For each land suitability group in combination with each crop rated suitable according to Table 4.27 a study of the economic prospects was made, by calculating per hectare: man days, machine days, animal days, seeds, fertilizers, pesticides, transport, packaging materials, other recurring costs, fixed costs (10% of recurring costs) and production. For expression in common monetary terms outputs were expressed in retail prices, inputs in consumer prices. Land rent was not considered. From this input-output study the labour income per hectare was calculated as well as the amount of labour that could be employed per hectare. Crops that provided too low a daily labour income (less that 30 escudos at 1971 prices) were not considered further.

b) Crop priorities: By rating labour absorption and labour productivity per hectare (scale 1-100) and multiplying them, a compound index was developed to indicate the crops of highest priority for each land suitability group, according to the government's own criteria of optimal land use. The criterion of minimum capital investment was discarded because of its insignificance compared with the other criteria.

c) Market limitations: Once the crop priorities were known the percentage share of each crop for each land suitability group had to be calculated for the crops with market restrictions. The following percentages of total acreage to be occupied with *chacra* were established (IICA/CORA, 1971, p. 49):

Crops	Maximum percentage of total *chacra*	Land capability classes
water melon + melon	10%	Ir, IIr, IIIr, IVr
melon	10%	Ir, IIr, IIIr, IVr
water melon	5%	Ir, IIr, IIIr, IVr
tomato	10%	Ir, IIr, IIIr
tobacco	10%	Ir, IIr
sugar beet	20%	Ir, IIr, IIIr

NOTE: It should be noted that the land capability classes not the land suitability groups have been used for this Table. The percentage of the land that may be used for the crops in question has not been related to differences in land capability, e.g. the same percentage of 10% for melon goes for classes I,II, III, IV.

d) Crop rotations: For purposes of rational land use and soil conservation the land use intensity

$$\frac{\textit{chacra} + \text{cereals}}{\textit{chacra} + \text{cereals} + \text{forage crops}}$$

needs to be carefully selected (all agronomic groups to be expressed in years). The National Agricultural Planning Office (ODEPA) established the following land use intensity criteria for crop rotations:

Land capability class	Medium to light texture	Heavy texture
Ir	4/5	-
IIr	3/4	2/4
IIIr	3/5	2/5
IVr	2/5	1/5

Taking into account also the availability of irrigation water rotations were selected for each land suitability group (see Table 4.31, from IICA/CORA, 1971, p. 51).

e) Crop choice and optimal land use: to meet the government's criteria for optimal land use, the crops corresponding to each agronomic group in the rotation had to be selected in such a way that the labour absorption and the labour income per hectare are maximal for each land suitability group A-N. The general sequence for all rotations is: *chacra*-cereals-forage crops. The sequence of individual crops is optimized using agronomic criteria (placing the most demanding crops first, e.g. regarding their fertilizer and phyto-sanitary requirements) and economic criteria. The proportion of each crop in the agronomic groups depends on the market restrictions and the compound index for crop priorities already mentioned.

For each resulting crop rotation the monthly and yearly labour income and labour demands are calculated. To minimize the labour peaks during months of highest labour demand, alternative rotations were made

Table 4.31 Rotation schemes: percentage share of *chacra*, cereals and forage crops for different land suitability groups

		Suitability groups													
		Class Ir		Class IIr				Class IIIr				Class IVr			
Land use intensity		4/5	4/5	3/4	3/4	2/4	2/4	3/5	3/5	2/5	2/6	2/5	2/5	1/5	1/5
Agronomic groups		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Chacra	1st year	20%	20%	25%	25%	25%	25%	20%	20%	20%		20%			
	2nd year	20%	20%	25%				20%							
	3rd year	20%													
Cereal			20%		25%		25%		20%	20%	20%		20%	20%	20%
Cereal-forage		20%	20%	25%	25%	25%	25%	20%	20%		20%	20%	20%		
Forage	1st year	20%	20%	25%	25%	25%	25%	20%	20%	20%	40%	20%	20%	20%	20%
	2nd year					25%		20%	20%	20%	20%	20%	20%	20%	20%
	3rd year									20%		20%	20%	20%	20%
	4th year													20%	20%
Totals		100	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: IICA/CORA, 1971, p.51

for each land suitability group. From these the optimal rotation can be selected by using a compound index which considers four variables: percentage of available labour that is absorbed, number of man equivalents engaged, labour income per hectare and labour income per calendar day.

Conclusion

Stage II, socio-economic analysis, relies heavily on the results of the preceding (10-year-old) physical land evaluation. Information produced during the physical land evaluation should be as specific as possible in defining the land utilization types and in defining the land suitability/capability classes. A rating of productivity for individual or groups of similar land (mapping) units is very useful. The reliability of information and maps produced during stage I should be clearly stated.

The observations made may have lost some of their relevance in the light of political changes which have since occurred in Chile. Nevertheless the IICA/CORA approach represents an interesting attempt to make use of the results of physical land evaluation in socio-economic land use planning.

Appendix 2: Land qualities and component properties in Brazil [1]

a) Deficiency of natural fertility, which in this case means chemical fertility, depends on:

1. the availability of the macro- and micro-nutrients in the soil, and
2. the absence or presence of soluble salts, especially sodium. Some other important toxic substances, such as soluble Al and Mn, are toxic, because they depress the availability of some mineral nutrients. These toxicities are considered as part of point 1).

Easy-to-interpret data on the availability of macro- and micro-nutrients are not available. The best relations between fertility status and other data which have been used till now in defining the fertility status are: base saturation (or Al saturation $\frac{Al^{+++}}{Al^{+++} + S} \times 100$), total exchangeable bases, and activity of organic cycle (forest against savannah).

Many more data are present which are relevant to the fertility status, directly or indirectly, but which cannot be clearly interpreted in terms of soil fertility. They include: total nitrogen, C/N quotient, total P_2O_5, Fe_2O_3, exchangeable cations, exchangeable Al, and exchange capacity. Other properties, such as soil depth and biological activity, water deficiency and oxygen deficiency, are also influential.

Field observations have to be used too, because it is mostly impossible to draw a final conclusion about the natural fertility of a tropical soil solely on the basis of the available chemical data. Observations about land use, yields, qualities of pastures etc., as well as the relationship between natural vegetation and natural fertility, will help in establishing the class or classes of the natural fertility of a given soil unit.

Degrees of limitations due to NATURAL FERTILITY

The classes of 'no' and 'slight' limitations are combined in the following definition, but should be split in a future revision.

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[1] *Source: Beek, Bennema and Camargo, 1964 (slightly revised)*

NO/SLIGHT LIMITATION

Soils with a high level of available plant nutrients, and without toxic salts due to soluble salts or exchangeable sodium. When the other four factors are also favourable, nutrient reserves allow good yields for many years for the more demanding crops too.

Profiles of Non Hydromorphous soils with latosolic B or textural B belonging to this class normally have more than 35% base saturation in the solum or less than 50% Al^{+++} saturation ($\frac{Al{+}{+}{+}}{Al{+}{+}{+} + S} \times 100$) and the sum of exchangeable bases is higher than 3 meq per 100 g soil. Further, the solum is practically free of excessive salts, conductivity less than 4 m.mhos/cm. The soils of humid and sub-humid tropical regions of Brazil belonging to this group are usually covered by forest.

MODERATE LIMITATION

1. Soils in which the reserve of one or more available plant nutrients is small, (this nutrient reserve may be present in the organic cycle, which includes the vegetation as well). When the other factors are favourable, nutrient conditions only permit good yields of annual crops during the first few years - after that yields decrease rapidly when agricultural use of the land continues. These soils need fertilizer after a few years to extend and maintain productivity, as otherwise they are likely to deteriorate and degrade into lower productivity classes as a result of exhaustive use.

The soils that belong to this group and are situated in the humid and sub-humid Tropics are usually covered by forest.

2. Soils with salt toxicity resulting from soluble salts and exchangeable sodium) on which sensitive crops will not grow. Conductivity normally 4-8 mmhos/cm.

STRONG LIMITATION

1. Soils in which one or more of the available nutrients only appear in small quantities. When the other factors are favourable, nutrient conditions permit only reasonably good yield for adapted crops, yields of the other crops being very low (likewise pastures are low-yielding).

To be used profitably these soils generally need fertilizing from the time they are first exploited.

The non-hydromorphic soils belonging to this class normally have low total exchangeable bases. In the humid and sub-humid Tropics these soils have a tree shrub cerrado vegetation, or a closed cerrado vegetation, or exist as exhausted agricultural lands.

2. Soils with toxic salt toxicity due to soluble salts and exchangeable sodium which only permit the growth of salt-tolerant plants, seriously damaging other plants.
Conductivity normally 8-15 mmhos/cm

VERY STRONG LIMITATION

1. Soils with a very restricted nutrient content, leaving them with practically no possibility of agricultural, pasture or re-forestation use.

These soils are in Central Brazil connected with cerrado and campo cerrado (savannah vegetation), and have very low sum of total exchangeable bases.

2. Soils with salt toxicity, due to soluble salts and exchangeable sodium, which only permit very salt-tolerant plants to grow. Bare spots and salt crusts may occur.

Without desalinization these soils have only restricted possibilities for use as pasture or extensive grazing. Conductivity normally more than 15 mmhos/cm.

b) Deficiency of water is in many cases primarily the result of the climate, especially of precipitation and evapotranspiration. In extreme cases, the climatological factors may even be the only important factors, e.g. in the desert and in some super-humid areas; but in other cases soil factors also have an influence.

In well drained soils the amount of available water that can be stored is critical; this amount depends on a set of single soil properties, including texture, kind of clay, carbon content and effective soil depth. In the case of not so well drained soils, as well as the amount of available water that can be stored, the presence and depth of a water table, together with the hydraulic conductivity, also have important influence on the availability of water in a certain soil.

The data on precipitation and evapotranspiration, as well as those on physical soil data, are, however, too scarce to allow conclusions to be drawn about the class of water deficiency a certain soil belongs to. Other data, such as the reaction of pastures and crops in the dry period, and also the kind of natural vegetation, may help in classifying the soil according to water deficiency. This is especially evident in cases where vegetation is adapted to wet soils, and also in the case of a tropical forest.

The tropical forest may be divided into the following groups:evergreen, semi-evergreen,semi-deciduous and deciduous. These groups,from evergreen to deciduous, are an expression of the increase in the deficiency of water, and they can be related directly to the different classes of water deficiency of the soil in question. The reaction of the forest, however, does not always seem to agree with the deficiency of water for crops, especially in cases where the rooting possibilities for forest trees are evidently much better than for many annual crops. Coastal terraces in Pernambuco with a hard A_3/B_1 (fragipan) are an example of this. One should therefore be alert that deficiency of water may be more than the forest indicates.

Degrees of limitations due to WATER DEFICIENCY

The degrees of limitations are defined in terms of water shortage for plant production during a shorter or longer period of the growing season.

NO LIMITATION

Soils in which the deficiency of available water does not limit plant growth and/or agricultural use.

a) Soils with free internal drainage belonging to this class are found in climates with no dry season.

b) Soils with a water table belonging to this class may also occur in climates with a dry season.

c) Irrigated soils may also be included in this class.

SLIGHT LIMITATION

Soils in which a small deficiency of available water occurs during a short period, which is part of the growing season. Growth of all plants is still permitted, but the growth of the most drought sensitive plants is limited.

a) Soils with free internal drainage belonging to this class are found in climates with a short dry season, 0-3 months. In tropical climates the natural vegetation in these conditions is usually semi-evergreen forest.

b) Soils with a water table belonging to this class can also occur in climates with a longer dry period.

c) Irrigated soils may also be included in this class.

MODERATE LIMITATION

Soils in which a considerable deficiency of available water occurs during a rather long period. The growth of plants which are not very sensitive to drought is possible; sensitive plants are harmed.

a) Soils in this class with free drainage are only found in climates with a rather long dry season, 3-7 months, if the soils are sandy and shallow, or in climates with a short dry season. In tropical climates the vegetation of this class, if it is forest, is normally semi-deciduous.

b) Soils with a water table or with temporarily stagnating water, belonging to this class can also occur in climates with a long dry period.

STRONG LIMITATION

Soils in which a great deficiency of available water occurs during a long period. Only very tolerant crops can be grown.

Soils belonging to this class are found in climates with a long dry period, longer than 7 months, and in climates with a rather long dry season (3-7 months), if the soils are sandy or shallow.

VERY STRONG LIMITATION

Soils in which a very great deficiency of available water occurs during a very long period, with a very short growing season, and where a growing season may be completely absent. The vegetation is often scarce, or only present during part of the year.

c) Deficiency of oxygen is normally caused by excess of water, and is mostly directly related to the drainage class, which is the result of climatological conditions (precipitation and evapotranspiration), local relief, and soil properties. In soils with a water table, the height of the water table is particularly important. In soils without a water table the critical factors are: the structure of the topsoil and the permeability of soil and subsoil, and if a more permeable topsoil is present, the depth of the less permeable layer.

It is evident that, in general, a direct relation must exist between drainage class and oxygen deficiency, because the drainage classes are defined in terms of excess of water. However, some discrepancies may exist in practice because the essential point when classifying according to oxygen deficiency is the reaction of plant life, while the drainage classes are defined according to soil profile characteristics.

This discrepancy between drainage class and oxygen deficiency is obvious in those areas of hydromorphic soils where artificial drainage is the common practice. Neither excess of water nor deficiency of oxygen may be present in such cases, although the drainage class based on profile characteristics may still be 'poorly drained'.

It must be noted that deficiency of water and deficiency of oxygen are here seen as two independent factors affecting the agricultural soil conditions, because a soil lacking water in one (the dry) season may show an excess of water in the rainy season. However, not all combinations of classes with lack of water and lack of oxygen are possible. With a great deficiency of water, the lack of oxygen will, for example, never be more than slight.

The occurrence of floods, which, next to a temporary deficiency of oxygen, also cause mechanical damage to plants not adapted to them, is considered as a separate factor in the rating of lack of oxygen.

Degree of limitation due to DEFICIENCY OF OXYGEN

In soils that are not artificially drained the degrees of limitation due to the deficiency of oxygen are closely related to the natural drainage classes of the soil. This relation is given after each definition.

NO LIMITATION	Soils in which the aeration is not prejudiced by the effect of water during any period of the year. Normally well or excessively drained soils.
SLIGHT LIMITATION	a) Soil in which plant roots that are sensitive to a certain deficiency of air are adversely affected during the rainy season, when the aeration worsens because of excessive water. Normally moderately well drained soils.
	b) Soils with permanent risk of slight and occasional overflow causing some crop damage.
MODERATE	a) Soils in which plant roots that are sensitive to a certain deficiency of air cannot develop satisfactorily, because the soil aeration is adversely affected by excessive water during the rainy season. Normally imperfectly drained soils.
	b) Soils with a permanent risk of overflow, causing crop damage.
STRONG LIMITATION + VERY STRONG LIMITATION	a) Soils on which plants which are not adapted to excessive water can only grow satisfactorily if artificial drainage is provided. Normally poorly or very poorly drained soils.
	b) Soils with frequent overflow causing crop damage.

d) The susceptibility to erosion. Water erosion is most important: aeolian erosion has not been very important in the areas surveyed until now in Brazil. Susceptibility to erosion by water not only depends on climate, topography and soil, but also on the land use, and on the natural vegetation. The standard for susceptibility to erosion is the erosion that would occur if the land were used for agriculture, growing crops that are not specifically soil-protecting and neglecting to take measures to prevent erosion. The susceptibility not only depends on climatological factors (especially rainfall distribution), degree of slope, slope length, and micro-relief of the slope, but also on the following soil factors: infiltration rate, quantity of water which can be stored until the soil is saturated, permeability, coherence of the soil material (with its variations in depth of the profile), the presence of stones on the surface which may act as soil protectors, and presence of slip surfaces in the subsoil.

Most of these soil properties are complex and in turn are the result of other, single or, at least less complex properties such as structure, texture, kind of clay, soil depth etc. The soil properties of friable latosols suggest that these soils are generally not very susceptible to erosion and indeed they are less susceptible than the slope would suggest. Shallow soils of the Sertão area (semi-arid North East) such as 'Cabrobo' and 'Vermelho do Sertão' and also Solonetz, are examples of soils in which the profile characteristics are unfavourable as far as erosion hazard is concerned. Red-Yellow Podzolic soils are often in between these two extremes.

Previous erosion which has removed the more porous and often more coherent topsoil and has initiated a system of rills and gullies, is often a factor making the soils still more susceptible to erosion. In the case of soils with a shallow solum on deep, non-coherent C-material, the erosion of this solum may lead to a disastrous development, in which the C-material is rapidly eroded. It must be noted that erosion by changing the soil also greatly influences the degrees of limitation of the other agricultural soil conditions.

The class of susceptibility to erosion to which a certain soil belongs can obviously best be determined in cases where these soils are used for agriculture without measures to prevent erosion. These observations of real data together with a fundamental knowledge about the relations between the susceptibility to erosion and land characteristics, provide a useful guide for rating erosion susceptibility.

Degrees of limitations due to susceptibility for EROSION

NO (+practically NO LIMITATION)	Soils that are not, or practically not, susceptible to erosion. 'If used for agriculture' erosion is absent or nearly absent in the greater part of the area. The A-horizon is intact also 'if used for agriculture' during a longer time. In general, soils that are level or soils that are nearly level and have good permeability. The very slight erosion that might occur in this class can normally be controlled easily.
SLIGHT	Soils that are slightly susceptible to erosion. 'If used for agriculture' erosion is recognizable by slight phenomena (SSM-Erosion Class 1, p.262); however, soil damage only occurs after prolonged agricultural use. In general, A-horizon still present, but part may

be removed; approximately 25-75% of the original A-horizon may be lost from most of the area 'if used for agriculture' (SSM).

In general soils that have gentle slope (3-8%) and good or rather good physical soil conditions; the soils may sometimes be sloping if the physical soil conditions are very favourable.

Protection and control mostly easily feasible under modern management, the use of selected crops (sugar cane) or tree crops will generally satisfactorily protect against erosion, as well as cultivating the land in small plots only.

MODERATE LIMITATION

Soils that are moderately susceptible to erosion. 'If used for agriculture' erosion is recognizable by moderate phenomena in the greater part of the area (SSM - erosion class 2); soil damage will be rather rapid: at first removal of the whole A1-horizon, which extends to the formation of rills and gullies.

In general, soils on a sloping or strongly sloping surface (8-20%), also when the physical soil conditions are poor or rather poor. The land may be moderately steep (20-40%) when the physical soil conditions are very favourable, or gently sloping (3-8%) when the physical soil conditions are very unfavourable.

Protection and control may be easily feasible, but in general will be more intensive, requiring more investment and knowledge and more expensive maintenance. Tree crop cultivation without the entire removal of the protecting vegetation cover may still be possible.

STRONG LIMITATION	Soils that are very susceptible to erosion. 'If used for agriculture' erosion is recognizable by strong phenomena in the greater part of the area (SSM - erosion class 3); soil damage will be rapid. In general, soils on moderately steep or steep land (20-40%), when the physical soil conditions are good or rather good. Land may be very steep when the physical soil conditions are extremely good, and strongly sloping (8-20%) soils when the physical soil conditions are unfavourable. Protection and control will mostly be very difficult and expensive, or not feasible.
VERY STRONG LIMITATION	Soils that are extremely susceptible to erosion. 'If used for agriculture' these soils will be destroyed within a few years. If used for grazing, the risk of soil damage is still great (SSM-erosion class 4). The damage includes a rapid removal of the A-horizon and eventually of other horizons, and very easy development of deep gullies. This class includes soils on very steep slopes (more than 70%) whose physical soil conditions are extremely favourable, and soils on steep slopes (40-70%) when the physical soil conditions are unfavourable. Protection and control of the erosion in this class is normally neither technically nor economically feasible, whether the soil is being used for agriculture, tree crop cultivation or even extensive grazing.

e) Impediments restricting the use of agricultural implements (mechanization)

This typical agricultural factor depends on slope, absence or presence of stones or rocks, absence or presence of extreme shallowness of the soil, at least if underlain by consolidated material or by material unfavourable to being ploughed up, bad drainage conditions, and an extreme constitution of the soil material, such as clayey texture with the presence of 2:1 layer silicate clays (often together with bad drainage conditions), organic soils, or loose sandy soils. Extra impediments in the microrelief include large numbers of ant-hills, termite mounds, or many gullies due to erosion.

If mechanization is contemplated, it should be noted that an area that has no impediments to mechanization should be larger than the defined minimum size to be of importance. Small areas that do not prevent problems to mechanization, but are scattered among other areas which do not allow mechanization, can be neglected.

It must be noted that the preceding five aspects (a - e) do not represent all the agricultural soil conditions. The condition of the tilth, for instance, is important for the germination of many seeds and is difficult to evaluate in any of the five aspects mentioned. Beside soil conditions, other conditions e.g. temperature and light, and conditions related to biological environment, are important in view of possibilities for agricultural use.

As follows from the foregoing, soil properties may have influence on only one of the five agricultural conditions, or on more than one. Most chemical properties only influence the fertility status, while slope influences at least 4 factors: water deficiency, excess of water (as part of local relief), susceptibility to erosion, and mechanization. Soil depth even influences all five aspects of agricultural soil conditions.

Degrees of limitation for the use of agricultural implements (MECHANIZATION)

NO LIMITATION	Soils on which all types of agricultural machinery can be used without difficulty during the whole over most of the area. Tractor efficiency (=% of tractor hours effectively used) more than 90%. These soils have a level topography, with slopes of less than 8% and show no other relevant impediments for mechanization.
SLIGHT LIMITATION	Soils on which most agricultural machinery can be used without, or with slight difficulty on most of the area. Tractor efficiency 60-90%. These soils have: a) Slopes of 8-20% with a gently undulating, undulating or sometimes hilly topography, when no other more serious impediments are present. In this class, the use of power-operated equipment (tractors) is still possible. Contour cultivation will be necessary. b) Level topography with slight impediments due to stoniness (0.05-1%), rockiness (2-10%) or shallowness. c) Level topography with slight impediments due to sandy texture, or clayey texture with presence of montmorillonitic clays or illitic clays; heavy textured soils may also present slight impediments due to lack of drainage systems or irregular drainage systems (compact soils with low permeability which can be very hard during the dry season).

MODERATE LIMITATION

Soils on which in the greater part of the area only the lighter types of agricultural equipment can be used, sometimes only part of the year; draft-power provided by animals. If tractors are used, tractor efficiency less than 60%.

These soils have:

a) Slopes of 20-40% with a topography which is usually hilly. There are no other more serious impediments to mechanization. 'If used for agriculture', frequent and deep erosion rills may be present.

b) Slopes less than 20%, but with moderate impediments due to stoniness (1-15%), rockiness (10-25%) or shallowness.

c) Level topography with moderate impediments due to sandy texture, or clayey texture, with presence of montmorillonitic or illitic clays; heavy-textured soils may also present moderate impediment due to lack of drainage or presence of a very irregular drainage system (compact soils, with low permeability, which are very hard during the dry season).

STRONG LIMITATION

Soils which in most of the area can only be cultivated with the use of hand tools. These soils have:

a) Slopes of 40-70% in a mountainous topography, or a topography that may be partly hilly. 'If used for agriculture', a pattern of frequent, shallow or deep erosion gullies may be present, being a strong impediment for the use of agricultural machinery.

b) Slopes of less than 40% with strong impediments due to stoniness (15-40%), rockiness (25-70%) or shallowness.

VERY STRONG LIMITATION	Soils which cannot, or only with great difficulty be used for agriculture; no possibility for drawn implements or even hand implements. These soils have:
	a) Slopes of more than 70% in the mountainous topography and escarpments.
	b) Slopes of less than 70% but with very strong impediments due to stoniness (more than 40%) rockiness (more than 70%) or shallowness, or 'if used for agriculture', a frequent pattern of shallow or deep gullies may be present.

5. Towards a systems approach in specific purpose land evaluation

In view of the many variables and disciplines involved, data analysis in land evaluation can be expected to become more and more complex. Facing a similar situation of growing complexity, disciplines bordering on land evaluation are relying increasingly on systems analysis and simulation to solve their data-handling and analysis problems, e.g. in land and water management (Kowalik, 1973; Carr and Underhill, 1974; Fleming, 1975; Hillell, 1977), agronomy and biology (Rose *et al.*, 1972; Patten, Ed., 1971, 1973; Arnold and de Wit, Eds., 1976).

Soil science, the discipline that in the past has probably been most actively engaged in land evaluation, is also following suit (Trudgill,1977). Dijkerman (1974), discussing the role of models in studying natural soil systems, pointed out that two sorts of models were required: genetic, to help explain the origins and development of soils, and functional, to help explain how the soil system operates and may therefore be controlled.

Pedologists have traditionally favoured the genetic approach so useful in land resources inventory for understanding the spatial variation of the soil properties. Land evaluation will benefit greatly from more functional studies that examine the interrelationships between land properties (qualities) and e.g. crop growth. These functional studies should involve consideration of all the pedological, biological, climatological, and physicochemical aspects of plant growth.

When dynamic models of plant growth (Van Keulen, 1975; Arnold and de Wit, Eds., 1976; de Wit *et al.*, 1978) based on fundamental processes that can be explained by general scientific laws are compared with the methods of land evaluation in use today, the gap that exists between them must be accepted. While attempts should be made to narrow this gap, land evaluation should meanwhile develop its own laws and deductions, based on known relations between land and land utilization. Since systems analysis has apparently been useful in solving complex problems in different fields of science and engineering, this final section will examine what systems analysis can do for land evaluation. To arrive at a more rational approach to the complex multidisciplinary land evaluation broadly outlined in Chapter 4 of this report, is it worth further refining the identification of underlying key variables, parameters and relation structures? This question must be answered.

5.1 The data-analysis problem

The most difficult part of land evaluation is the data analysis, when the various data about land utilization types and land mapping units are brought together and compared. Data analysis should result in a land suitability classification.

The comparison between land utilization and land becomes even more complex when variable physical inputs for improving the land units are taken into account, giving rise to variable outputs that depend on the types and amounts of inputs applied and the responsiveness of the land units to such input applications.

In reconnaissance-type land evaluations the levels of constraining land qualities are normally interpreted very generally according to the production and other effects to be expected from a land utilization type that uses standardized levels of input. In most cases each land unit will be evaluated concomitantly with each of the land utilization types selected for the study area. The time-variant character of land and land use is broadly analysed by taking into account roughly defined climatic seasons and hazards.

The principal purpose of data analysis in reconnaissance-type physical land evaluation is to eliminate from more detailed analysis those land units that are definitely unsuitable for the land utilization types under consideration. Usually, only a few standardized levels of input and output suffice for this purpose:

outputs	*inputs*	*land suitability*
high	low	high
high	high	medium
low	low	medium
low	high	low

The reconnaissance-type land evaluations of Brazil, described in Section 4.3.4 are examples of this.

Detailed land evaluation requires a more refined analysis including simulation of inputs and corresponding outputs. The land qualities and the physical inputs will need to be handled as interrelated variables controlling the fundamental land utilization processes and the resulting outputs. Such a selective method of input and output prediction requires the continuous land use process to be split up into a number of specific activities taking place during finite time periods: land preparation, sowing, vegetative growth, etc. as was explained in Section 3.2.

Because this kind of data analysis is more complex, the only land utilization types considered are those that are really promising for the land in question.

In detailed land evaluation there is a definite shift in emphasis from a suitability classification to an analysis of physical inputs and corresponding effects – first in physical and then in economic terms, e.g. the specification of management, improvement and conservation practices and corresponding effects; amounts of fertilizers, water applications, subsurface drain spacing, and yields.

The discussion in Section 4.3 on land evaluation in Latin America revealed that the prevalent data-analysis techniques in that part of the world consist of conversion tables that relate diagnostic soil/land properties or qualities directly to different classes of land capability/suitability.

Physical inputs are considered mainly to enable land suitability *with* improvement to be distinguished from land suitability *without* improvement. Only a few levels of input are considered: low-medium-high. The Brazilian methodology also uses input levels as a criterion for land suitability class distinction. Land requiring high inputs for improvement is excluded from class I.

More detailed land evaluation studies have been confined to irrigation, drainage, desalinization, soil conservation and soil fertility studies (e.g. Alva *et al.*, 1976; Chanduví, Ed., 1973; Sanchez, 1973, 1976; Bornemisza and Alvarado, Eds., 1975). The more detailed observations and measurements of cause-effect relations underlying such problem-oriented studies are mostly carried out by specialists in the fields of soil and water management, with the specific purpose of providing site-specific information for land evaluation, to complement the observations of the soil surveyors.

Although detailed investigations can be made for special projects, it will be impossible to carry out site-specific research on all land units, and for all relevant types of land utilization for lack of sufficient time to suit all needs of land evaluation and land use planning. There will thus always be a need to predict land use performance by analogy.

5.2 The temporal problem

Land use and its elements land and land utilization type are dynamic systems, not merely because they depend on variable weather conditions, but because they alter with time. The analysis of dynamic systems is necessarily complex.

A distinction should be made between time-variant processes and land (use) changes that take place within one cycle of the continuous land use process ('repeating systems'), and those that are part of a normally much slower and irreversible process of change: the long-term trends in land degradation, land improvement and land use ('transforming systems'). Land evaluation and land use planning normally make proposals for the shorter-term cyclic land use activities of repeating systems that take into account a certain control of the longer-term dynamic processes, which may be strongly influenced by these shorter term land use activities. Well-known criteria serving this purpose are sustained productivity and the conservation of environmental qualities such as water and soil resources.

Probably the best known example of dynamic systems analysis in land use planning is the preparation of cropping calendars. Cropping calendars are the basis of dynamic systems analysis in land evaluation. However, optimal timing of the various land use activities is only one aspect of dynamic systems analysis; we also have to find the best input-output relations for each separate land-dependent activity, taking into account that a decision about inputs for one activity may affect such decisions for other activities, and the input-output relations of the land use as a whole. For a dynamic analysis of the total land use performance it will be necessary to have a data-analysis system with good possibilities for feedback between the various partial analysis of separate land use activities. For practical reasons, data analysis will be limited only to land use activities that are possibly constrained by one or more land qualities, with a significant effect on the overall performance of the land use or on the quality of the environment.

In Section 3.1 the dynamic character of land qualities and land requirements that describe the land and land utilization has been simplified by describing their values during finite time periods. During such time periods the factors describing the land use system are assumed to be time-invariant, for land evaluation convenience' sake. The duration of such finite time periods and the timing of time-dependent activities will depend on the weather experienced by the land unit and on the activities and processes of the land utilization type.

The land qualities defined in Brazil (Section 4.3.4) describe their variable status during one cycle of the land utilization type. The levels describing their status refer to specific time periods pertinent for the land use, e.g. water deficiencies in the growing season, workability problems in the land preparation period. Each level represents a different sum of the conditions occurring during finite time periods that make up the cycle of the land utilization type. Little attention has been paid to the actual timing of such finite time periods.
More detailed land evaluation needs to pay more attention to cropping calendars in the definition and rating of land qualities.

When the weather is very erratic it will be necessary to add a probability distribution to the values found for the relevant weather-controlled land qualities. An example is Virmani's (1976, 1977) studies; he has applied systems analysis to estimate the crop moisture availability of two different soils for purposes of crop planning in the monsoon climate of the Hyderabad region of India. Another example is Wind's study (1976) on the influence of drainage on the seedbed preparation of heavy clay soils during the spring season in The Netherlands, taking into account a daily record of the weather conditions for a twenty-five-year period. In this study the land quality 'workability' has been estimated on a weekly basis, in combination with a probability that a certain pF value of the topsoil, critical for the land utilization in question will occur: 70%-80% or 90%.

An example of analysis of dynamic land requirements is the study by Slabbers and Herrendorf (1977) of the water requirements of alfalfa. This study produced criteria for irrigation during finite stages of the vegetative growth of this crop.

For purposes of data analysis in practical land evaluation, finite time periods of one week to one month are usually sufficient. More theoretical and partial analyses of dynamic systems may require more detail: the dynamic model of plant and crop growth described by de Wit *et al.* (1973, 1978) is based on hourly data-inputs of the key variables.

Fig. 5.1 is an illustration of dynamic systems analysis in land evaluation, based on three critical land use activities taking place at finite time periods t_1, t_2 and t_3. The factors LQ, LR, I and Y are handled as time-invariant for the mentioned finite time periods:

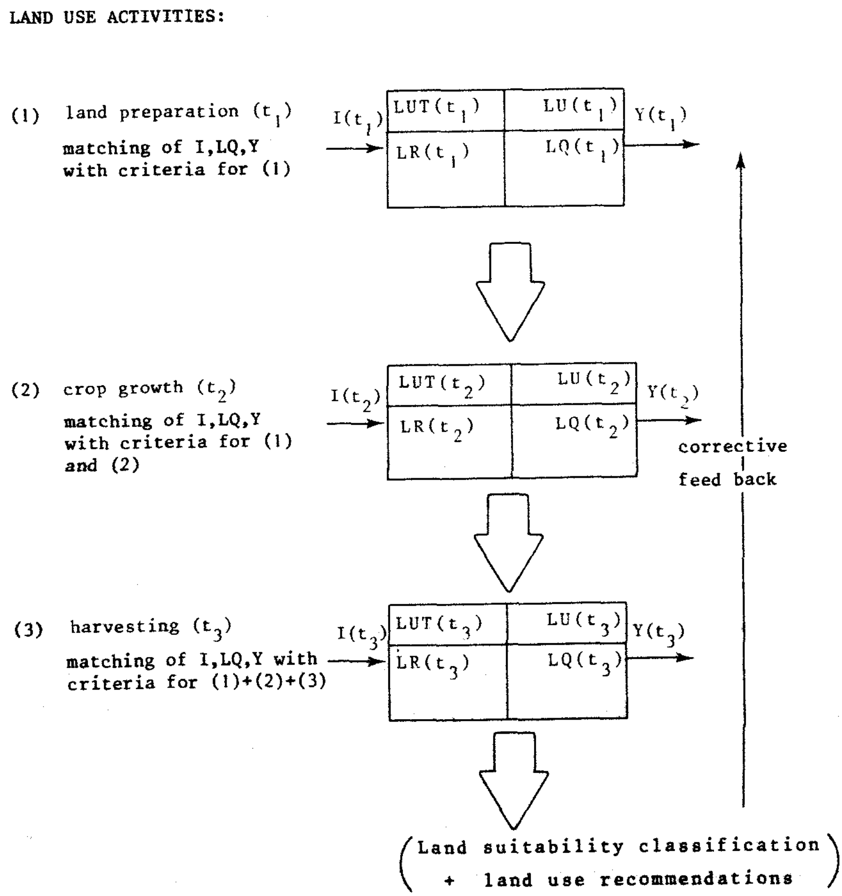

Fig.5.1: Dynamic systems analysis in land evaluation

Although the temporal problem can be managed by carrying out partial analyses of land use activities taking place during finite time periods there remains a need for some kind of dynamic systems analysis to solve two types of temporal problems in specific purpose land evaluation:

In the first place there is the problem of accurately measuring the values of the dynamic (and sometimes stochastic) variables and parameters for these finite time periods, e.g. the characterization of the land qualities 'available water' and 'workability', or of the land requirement 'water required for rapid vegetative growth'.

Secondly there is the need to integrate the results of the partial analyses for finite time periods into an evaluation of the total land use process. In this case too, the assistance of specialists in dynamic systems analysis, e.g. land use planners, may be required to prepare land use calendars, to time the application of variable physical inputs, select input application methods, etc.

In the next sections, systems analysis in land evaluation will be discussed mainly against the background of land use processes and activities taking place during finite time periods. The time variability of the main variables and parameters will be ignored as much as possible to avoid complications irrelevant to the discussion.

5.3 Systems analysis and simulation models

5.3.1 Systems theory

The aim of systems analysis is to construct common theoretical frameworks within which scientists of different fields can find a common language[1].

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[1] *This aim is also one of the objectives that originated the Framework for Land Evaluation (FAO 1976) and of the publications supporting it.*

Since systems analysis is relatively new to land evaluation it seems worth explaining some of its underlying concepts and principles, even though very sophisticated methods of mathematical modelling and computer simulation have been achieved in soil conservation (e.g.Fleming, 1974) and water management (e.g. De Ridder and Erez, 1977) to solve specific problems. At the risk of being criticized for superficiality, I present some definitions below and in Appendix 3 based mainly on Toebes's (1975) report and on De Wit and Goudriaan (1974).

The term 'system' has many meanings, varying from sets of interacting physical elements (e.g. the 'land' system, describing a mapping unit in some Australian reconnaissance resource surveys) to relations between land and user (e.g. the land tenure system) and to techniques of cultivating the land (e.g. the management system). Toebes observes that most systems have three things in common. These are:

- a collection of elements
- relationships between these elements
- a rationale for selecting elements and relationships

According to Toebes, a system is enclosed by a systems boundary which separates it from other systems over which the scientist has no control, but which are expected or known to be related to the system under consideration. These other systems represent the environment of the constructed system. The systems environment is part of the Universe that comprehends all kinds of systems that can be thought of, but which are not supposed to have relations with the system that is being considered. Against this background Toebes presents the following definition of the concept system:

- A system is a collection of elements and their relationships selected for their bearing on the questions being asked or the goals pursued and related to similarly selected systems in its environment.

Toebes's definitions seem to refer primarily to systems that have been designed by engineers and are therefore under their full control: the bridge, the railroad, the ship, the space craft. The elements of the system and the relations between them can normally be rationally chosen. But the elements and relations of biological systems are not a product of our choice: they are the product of creative, evolutionary, and other processes largely beyond our control. De Wit and Goudriaan (1974, p.2) when introducing the simulation of ecological processes define a system as a 'limited part of reality with related elements'. Examples of biological systems are a plant, a field, or a farm.

The engineer's definition of a system can be compared with a model of a biological system that has been constructed on the basis of well known elements of that biological system and of the relations between them. The description of a land (mapping) unit LU, no matter whether expressed in terms of land properties or land qualities, is a model of the real land conditions of the mapped area. The land use system LUS, constructed by combining a land (mapping) unit LU with the descriptive model of land utilization LUT represents a model (LUS_m) assumed to be relevant where land evaluation is carried out. It follows that strictly speaking the term *systems analysis* when used in the context of data analysis in land evaluation for agricultural purposes must be understood as 'simulation', defined by de Wit and Goudriaan (1974) as 'the building of a dynamic model (changing with time) and the study of its behaviour'.

The elements of a system may be of any kind, ranging from certain types of equipment in a farming system to the various phases (solid, liquid, gas) of a soil system and the physical components of mathematical systems. Toebes, Hanken et al. (1973) emphasize that increasing numbers of non-physical elements are incorporated into the system or are placed in its environment, e.g. the aesthetic qualities of the natural environment and ethical elements of the human behavioural system.

The attributes: elements generally have a number of properties, called attributes. Their specification requires measurement. Toebes also mentions the need (in environmental engineering) to specify the spatial and temporal variation of attributes which govern the frequency and accuracy of measurement.

De Wit and Goudriaan (1974) stress the convenience of choosing the boundaries between a system and its environment in such a way that the system is isolated. Since this is often not possible boundaries should be chosen so that the environment influences the system but the system does not affect the environment. The consequence may be that the system has to be expanded. An example from land evaluation is the expansion of the soil unit as the main reference for data interpretation into a land (mapping) unit by adding topographic, climatic and/or vegetation phases. De Wit and Goudriaan also suggest that if such expanded models become too large to handle, the interaction between the system and its environment can also be characterized by continuous measurement at the interface. In land evaluation we may thus decide to measure the impact of rainfall on soil erosion through continuous measurements at the soil surface.

As explained in Section 3.3 sometimes land evaluation has to consider the effect of the land use system on its environment (overall land suitability classification). Partial analyses of only the most important land use processes based on selected variables (overall LQ's and overall LR's) and a simplified relation structure should in many cases suffice to solve such problems of interaction between the system and its environment.

Relationships and systems structure have been explained by Toebes (in *Civil Engineering Systems Analysis*, Part II, Spring 1975 II-12 (GHT), B: 'Further Definitions and Simple Concepts', II Systems: Perspective Concepts and Procedures as follows:

- *Relationships* or ties between elements and between attributes of elements can also be of many kinds: flows of material; constraints on variables; mutual dependencies on a third element; etc. Given a set of elements, the network of relationships, called systems structure, defines the 'invariant part' of a system's 'behavior'. Hence a system's ability to implement a purpose, can vary greatly depending on the composition of the network of relationships or system structure.
- *Sub-systems*: Fuller specification of elements will usually permit one to see them as systems in their own right. Consequently, elements will often be refered to as sub-systems, SS. If one continues an hierarchical analysis, sub-systems may have sub-sub-systems, SSS, and so forth ...

For further definitions of important concepts in systems theory, see Appendix 3 of this report.

5.3.2 The rationale of a systems approach to land evaluation

The system to be analysed is the land use system (LUS) which for the purpose of land evaluation has been subdivided into two elements or subsystems: the land (mapping) unit, LU, and the land utilization type, LUT, as explained in Section 2.1.

The boundary between land and land utilization type is less distinct in the real land use system than in our model since systems analysis is necessarily arbitrary because it cannot take into account all interactions between land (LU) and land utilization type (LUT).For instance site-specific adaptations of a land utilization type (crop) to constraining land conditions, or the slow long-term side effects of the land utilization on the land (e.g. changes in physical soil properties and in micro-biological processes and activities) may sometimes be deliberately excluded for purposes of simplification. Another example of interaction between LUT and LU is the early uptake of nutrients by crops from the soil to be stored for use at a later time.

The key attributes of the land utilization types and the land qualities of the land mapping units are the most important elements of the subsystems LUT and LU, because of their influence on the inputs needed and on the outputs obtained.

Evaluation of the state of the key attributes of the land utilization type during finite time periods is the concern of agronomists and agricultural engineers who are expected to provide the land evaluator with specifications of the land requirements LR of each LUT. For the land evaluator these LR values are important system-parameters. Evaluation of the status of the land during finite time periods is the concern of the land evaluator. The land qualities are the 'state variables' of the land use system in land evaluation.

Other important variables of the land use system are the physical inputs (I) also known as 'input variables', 'control variables',or 'decision variables', and the outputs (Y) or 'output variables.

The focus during land evaluation is in the first place on inputs that control the outputs through manipulation of the land qualities.If in a land use system the conversion of inputs into outputs does not involve the land conditions, such inputs will not be subject of simulation but will be land utilization determinants underlying the land utilization type definitions (see Section 2.4). Examples are the foliar application of fertilizers based on foliar analysis of nutrient deficiencies, and the direct application of concentrates and minerals to cattle. Of course when such inputs have a significant modifying effect on the land qualities, such as the contamination of soils with heavy metals or phosphates derived from concentrates and contained in cattle droppings, the inputs responsible for such land degradation processes will need to be included in the systems nalysis.

The systematic breakdown of the land use system into measurable land qualities, land requirements, inputs and outputs is the foundation for a systems approach to land evaluation.

Toebes's definition rightly stresses that to make a systems approach meaningful specific questions should be asked or a goal should be pursued. De Wit and Goudriaan refer to the 'requirements of relevance imposed on the model' which determine the parts of the real (biological) system that need to be presented in the model.

The questions asked of land evaluation essentially concern the prediction of physical inputs (I), outputs (Y), changes in the values of the land qualities (LQ), and possible other effects if a particular land unit (LU) were to be combined with a specific land utilization type (LUT): in other words, the prediction of the performance of LUS.

This requires first of all techniques for measuring the pertinent factors already mentioned: LQ, LR, I and Y. To be able to do this the relations that exist between them must be described, particularly the I/LQ,LQ/Y and I/Y relations. (Relevant techniques that do this will be discussed in Section 5.4).

The goal pursued by land evaluation is ultimately the optimal utilization of land. To reach the desired goal of land evaluation,systems analysis includes the application of optimization techniques in order to find the 'best' LQ, LR, I,Y combination, based on explicit land suitability criteria, as will be explained in Section 5.4.2.

Toebes's definition of a system ends with the mention of other related systems. This is a very important observation for land evaluation, because land (mapping) units and land utilization types should not be analysed out of context. Therefore in Section 3.5 a distinction has been made between internal and overall land suitability classification.

Systems analysis in land evaluation as explained so far, can be represented diagramatically (see Fig. 5.2).

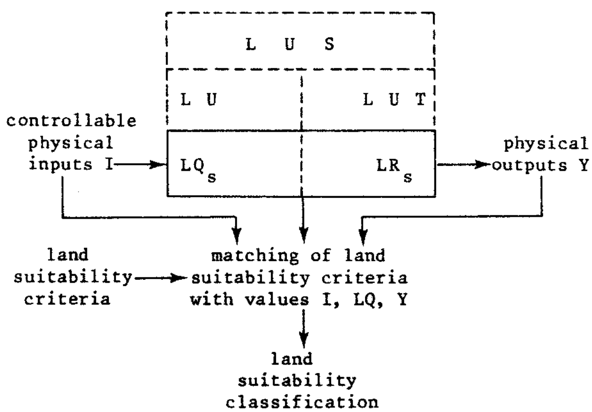

Fig.5.2: A diagrammatic representation of systems analysis in land evaluation.

The stages that a systems approach must adopt for land evaluation are summarized below:

I. Problem analysis: At the outset the development situation has to be assessed and relevant land utilization types must be identified. The most important limiting land qualities are recognized. Land suitability criteria are formulated. Problem analysis has been discussed in Section 2.4. Against the background of this information the activities to be carried out during the next stage are specified.

II. Abstraction: The selective process of observing the real systems, and measuring, classifying and mapping the pertinent information. Thus we arrive at abstractions or 'models' of the real systems. the land utilization types (LUT) and the land mapping units (LU). Land utilization types will often be models of uses that do not yet exist in the study area; sometimes their description can be supported by analogy with real systems existing outside the study area, otherwise such descriptions will be entirely hypothetical, and must be reported as such. It would be impossible to collect and describe all information that can be observed and measured about land and land utilization. Abstraction is necessarily a very selective process of data collection, limited to describing the characteristics of land and land utilization that are needed for the next stage, which is deduction.

III. Deduction: By systematically analysing the data collected we aim to deduce the effects produced when a specific land utilization type operates on a specified land (mapping) unit. This deduction is in two separate steps:

- input-output analysis: comparing physical inputs that will ameliorate constraining land conditions, their management and conservation, with the effects or 'outputs' to be expected from such inputs. Each input-output combination is handled as a separate option.

  This information is needed for the next step:

- land suitability classification: the suitability of a particular land unit for combination with a particular land utilization type is classified.

  Land units of comparable suitability are combined in the same land suitability class.

  During the land suitability classification the best input-output combination for each LU, LUT combination is selected.

This is the combination that places the land unit in the highest possible suitability class if operated by the land utilization type in question. Thus land suitability classification is a type of optimization process.

Land evaluation is part of a broader land use planning process, preceding implementation, which will not be further discussed here (see Section 4.1). Once the entire land use planning process has been completed and the necessary policy decisions have been taken, the cycle of systems analysis and simulation should be concluded with:

IV Realization: Land evaluation needs to be carried out in the knowledge that its results will eventually need to be implemented. Some of the weaknesses found in land evaluation and soil survey interpretation reports may be explained by the time lag between abstraction and realization. Abstraction will be served by occasional calibration of measurements and interpretations in places where land use changes have been realized after completing the entire cycle of problem analysis, abstraction, deduction and realization.

The rest of this discussion will be limited to the stages preceeding realization. Obviously, if the land is classified as 'unsuitable' for the land utilization type in question there should be no change in the present situation. Figure 5.3 summarizes the cycle that is followed in a systems approach to land evaluation (adapted from Hanken and Reuver, 1973):

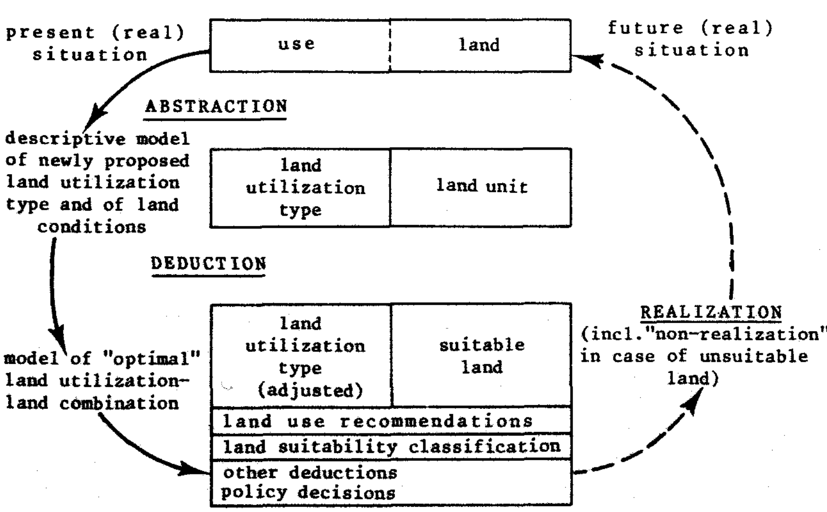

Fig.5.3: The cycle of a systems approach to solving land use problems.

Fig.5.4 presents a more detailed view of the systems approach to land evaluation.

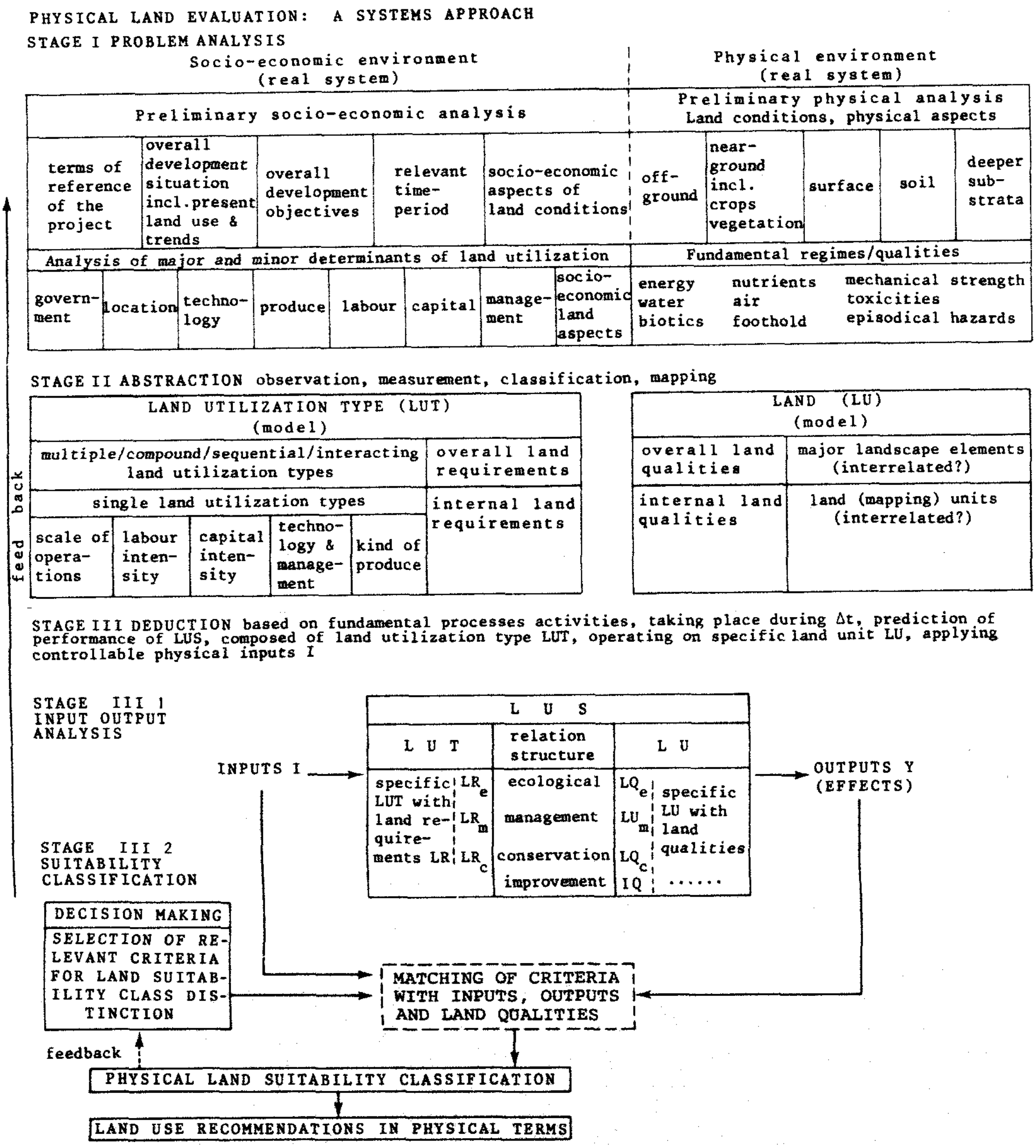

Fig.5.4: Physical land evaluation: a systems approach.

5.4 Descriptive and prescriptive systems analysis

In Fig. 5.4 the deductive stage III of physical land evaluation has been subdivided in two parts:

- stage III.1 input-output analysis
- stage III.2 suitability classification

This subdivision coincides with the basic distinction in systems theory between descriptive and prescriptive systems analysis:

Descriptive input-output analysis

Input-output analysis should be carried out not only to support the land suitability classification but also to provide the decision-maker with alternative land use changes.

Stage III.1 (Fig.5.4) has been designed to produce exactly that: for each land use activity likely to deviate from a standard input-output pattern, a range of alternative inputs is assumed and the corresponding outputs and effects on the land qualities calculated. In physical land evaluation this should result in sets of inputs, outputs and land qualities specified in physical terms: e.g. levels of fertilizers (I) and the corresponding yields (Y), duration, type of machinery work and the resulting soil compaction (LQ). The specification of these levels may be measured on an ordinal scale as indicated in Section 5.1 or on a ratio scale. This analysis of input-output relations is an example of what several authors on systems analysis (e.g. Toebes, 1975) have called 'descriptive systems analysis'. This investigates and describes. There is no question of choice or optimization: each input-output combination is analysed and described separately, without being compared with other input-output combinations. The fact that the range of inputs is restricted to those relevant for the given land utilization type does not alter the descriptive nature of this kind of data-analysis.

Descriptive input-output analysis can highlight undesirable outputs or effects on the land qualities resulting from certain inputs, which may not have been included in the decision-maker's set of criteria, e.g. the problem of salt accumulating in the drainage water when installing an irrigation project. (This salt is an output of the land use system, whereas the irrigation water added to the natural water supply of the land is a physical input).

NOTE: As mentioned earlier, descriptive systems-analysis is expected to play a greater role in the future; for example in the use of computerized and analogue models to characterize time-variant land qualities and land requirements, which in turn represent key elements for input-output analysis. This type of descriptive input-output analysis has much more than scientific significance if it is coupled with prescriptive systems analysis based on fundamentally social and economic criteria, related to clearly-defined goals of optimal land utilization. This combination of descriptive and prescriptive systems analysis is the basis of the systems approach presented here and also (perhaps less explicitly) of the land evaluation methodology developed for Brazil (Bennema, Beek and Camargo, 1964) and in the Framework for Land Evaluation (FAO), 1976).

Prescriptive suitability classification

During the deductive stage III.2 (Fig.5.3) the land evaluator's task is to bring order to the multiple information on input-output relations corresponding to a particular LUT, LU combination, and also in the sometimes great variety of land (mapping) units that have a certain measure of potential or 'suitability' for a particular land utilization type. To this end he should declare which input-output combination should be 'preferred' to give the 'best' land use performance. In addition, he should express preference for the suitability of different land (mapping) units for combination with the land utilization type in question.

The presuppositions and judgments underlying such a process of ranking should be acceptable to the user of the information, the decision-maker, or at least be made clear in the report.

Preferably, the land evaluator should not establish his own norms but base himself on norms formulated by the decision-makers. A clear exception is the environmental norms, often overlooked by decision-makers. The land evaluator has a major responsibility to help formulate environmental norms by giving the decision-maker the benefit of his familiarity in foreseeing hazards of resource degradation and in formulating alternative conservation measures.

The type of systems analysis leading to an answer to the questions 'what should the land be used for?' and 'how should it be used?' has been called in this report 'prescriptive systems-analysis' (Toebes, 1975).

Prescriptive systems-analysis implies several value judgments. To this end the land evaluator should base himself on the earlier mentioned land suitability criteria.

Prescriptive land suitability classification is a process of ranking land units according to their suitability for combination with a specified land utilization type into a specific land use system. This ranking should be carried out against the background of a specified Goal or Objective, which the land use system is supposed to meet or to approximate as closely as possible. The measure in which this Objective is met determines the degree or 'class' of suitability of the land unit for the land utilization type in question.

The presence of an Objective distinguishes prescriptive land suitability classification from descriptive input-output analysis.

Objective, land suitability criteria and Criterion Function

The Objective provides the ultimate rationale for placing land units into land suitability classes. The overall Objective of land evaluation is similar to that of all other studies of land and land use:

to contribute to the optimal use of the land, taking into account the local socio-economic and physical conditions and constraints. But such an expression of the Objective is much too abstract to serve specific purpose land evaluation. Therefore this Objective (Z) should be expressed in terms of a combination of more specific derived objectives (z) (Hanken and Reuver, 1973):

$$Z = (z_1, z_2, \ldots z_n)$$

Some of the derived objectives controlling the land suitability classification may at first appear to be conflicting or even irrational: combining the objectives of maximum yield, sustained performance and conservation of the quality of the physical environment may sound like making omelettes without wanting to break the eggs. When specifying the derived objectives these sources of conflict must be confronted.

Duckham and Masefield (1970, p.15) include the following derived objectives for a food-producing farming system: optimization of inputs, maximization of crop plant growth, minimization of plant and animal wastages, realization of an adequate economic return and the assurance that this return is reliable from year to year and persistent over decades or even longer.

De Wit (1975, p.159) formulates the broad objectives of agricultural land use as follows:

> ... should remain sufficiently productive to function as a source of income for farmers and agriculturally based industries, both up-hill towards the farm and down-hill towards the consumer, but also guarantee a reasonable diet for the population in times of international stress. At the same time agriculture should remain a source of employment, contribute its share towards a more efficient energy use, function as a source of land for urban development and semi-natural conservancies, rehabilitate valuable landscapes and in general lessen its effect on the environment.

Each derived objective needs to receive a certain weight or value which is realistic compared with the values expected to be taken by the other derived objectives. For reasons of simplification the term 'derived objective' will be further referred to as 'land suitability criterion' z_i. Each land suitability criterion z_i can be given a real value $v(z_i)$. Presentation of the objective Z in terms of v(z) is called the Criterion Function or simply Criterion (C) (Hanken and Reuver, 1973).

To specify the Criterion Function of a land suitability classification the land suitability criteria z_1, z_2, ..z_n are related to the values of corresponding input, land quality and output variables of the land use system. In principle, C is a selective collection of values of these variables. The selected variables are therefore also known as object variables or criterion variables. Output variables that are not selected for the role of criterion variables are also known as indifferent variables. They exercise no influence on the ultimate result of land evaluation. An example is the salinity of drainage water evacuated from an irrigation district, when its level is not a concern for land suitability rating. When land evaluation is only concerned with the on-site effects of land use there is a good chance that some output variables will be handled as indifferent variables, or not considered at all, since they have no effect on land use performance on the site itself. A distinction could be made between an internal and an 'overall' Criterion Function to highlight this problem (see also Section 3.3.). Examples of land suitability criteria have been given by Beek and Bennema (1972; see Table 5.1).

A great variety of criterion variables concerned with objectives concerning environmental quality and control have been listed in Vink, Ed., (1971) and Dassmann *et al.* (1973).

During the prescriptive systems analysis the best input-land quality-output combination is selected, that is the combination for which the Criterion Function is optimal. This requires firstly a precise definition of the Criterion Function, which is realized by specifying the values that each criterion variable should take to correspond with the different land suitability classes, i.e. the multi-dimensional Criterion Function vector is subdivided into trajectories corresponding to the different land suitability classes.

Table 5.1: Land suitability criteria

(A) BIOLOGICAL CRITERIA

choice of adapted crops (wide/limited)
yield (low/high)
performance reliability (regular/irregular)
multi annual yield trend (marginal net return rising/sustained/falling)

(B) SOIL MANAGEMENT CRITERIA

timing of field operations (flexible/fixed)
choice of adapted field equipment (wide/limited)
performance of field equipment (high/low)
seedbed quality (high/low)

(C) CONSERVATION CRITERIA

trends in land degradation (improving/sustained/falling)
change in landscape situation (improving/sustained/falling)
hazards for the introduction of endemic diseases (absent/present)

(D) DIVERSIFICATION CRITERIA

land resource allocation (enterprise proportions fixed/limited)
degree of land use intensity (intensive/extensive)
carrying capacity (close/far from proposed utilization)
resource use alternatives (many/few)
elasticity in selection of plot/farm size and shape (free/limited)

(E) ECONOMIC CRITERIA

employment absorption (high/low)
production costs (high/low)
benefits (high/low)
cost of land improvement (low/high)
repayment capacity of investments (high/low; short/long term)

Source: Beek and Bennema, 1972

Objective and Criterion Function are seldom clearly defined by the decision-makers ordering the land evaluation. Therefore the construction of Criterion Functions and the definition of land suitability classes may become a major task that requires considerable consultation between land evaluators and decision-makers. Land evaluators have an excellent opportunity here to ensure that proper weights are given to variables that affect environmental quality and the conservation of land resources.

It may be concluded that land suitability classification is a kind of optimization process: from the various input-output combinations identified during the descriptive input-output analysis, a combination is selected that places the land unit in the highest possible land suitability class for the given land utilization type.

Care must be taken that the land suitability class definitions are mutually exclusive to ensure that a certain (LUT,LU) combination will correspond with only one class. On the other hand the resolution of the land suitability classification should be such that each possible combination of values of criterion variables corresponds with one of the classes.

This discussion on Objective, criterion variables and Criterion Function has been summarized in Fig.5.5.

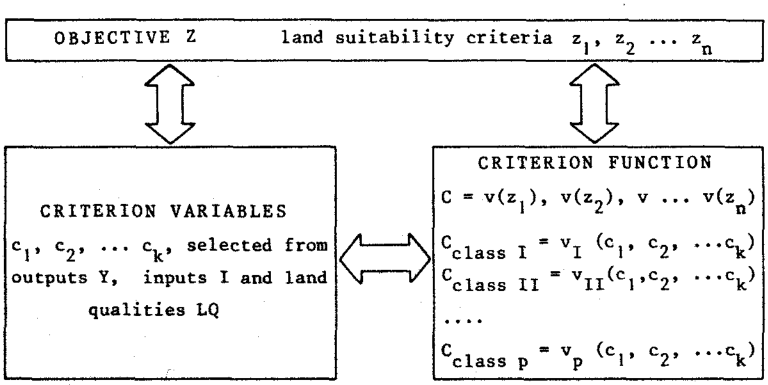

Fig.5.5: Specification of the land suitability classes 1, 2, ... P.

For example (Table 5.2): the Objective Z, optimal land use, can be expressed by two derived objectives or land suitability criteria z_1= maximum production and z_2= no soil erosion. The criterion variables that make up the Criterion Function are the output 'variable yield' and the output variable 'erosion losses'. The Criterion Function $C=F(c_1,c_2)$ reads: maximize c_1 with $c_2=0$, which can be translated into the following specification of land suitability classes I-IV:

Table 5.2 Specification of land suitability classes. An example

CLASS	c_1 -yield kg/ha	c_2 -erosion losses kg/ha
I	> 5000	0 -100
II	4000-5000 3000-4000	100-200 0 -100
III	3000-4000	100-200
IV	< 3000	> 200

The problem of commensuration

Difficulties can be expected when the values of different criterion variables need to be translated into a single commensurate value - the land suitability class - and when the best set of several alternative sets of values of criterion variables needs to be selected according to the Criterion Function.

As already mentioned, criterion variables are a selection of inputs, land qualities and/or outputs whose values are mostly expressed in physical terms of different dimensions: inputs expressed in tractor hours per hectare or amounts of fertilizer per hectare; land qualities expressed in terms of erosion or flooding hazard; outputs expressed in kilograms of harvestable produce per hectare.

The process of translating or converting the values taken by variables and parameters of different dimensions into a single commensurate value - the suitability class in our system - is known as commensuration. Commensuration usually results in an expression of value in monetary terms and is a common practice in economic analysis, which is mostly concerned with inputs and outputs to which prices can be easily added.

Commensuration becomes much more complex when land qualities are also included in the set of criterion variables and specific (monetary) weights need to be ascribed to each of them, e.g. to the value of erosion control, of flood control or of a reduction in the contamination of soil or drainage water (Locht, 1971; OECD, 1974; Opschoor, 1974; Wendt, Ed.,1976).

Physical land evaluation precedes the stage when prices are added, and is primarily concerned with criterion variables expressed in physical terms. Although sometimes commensuration in common physical terms will be successful, e.g. in grain equivalents or in calories, in most cases physical land evaluation should be prepared to carry out its analysis while maintaining the multi-dimensional nature of its Criterion Function and of the land suitability classes, as has already been demonstrated in previous examples.

The number and kind of criterion variables and the interactions between them determine how complex land suitability classification may become. The problems tend to be more pronounced in detailed land evaluations, when all kinds of specific inputs which have a variable influence on the outputs and on the land qualities need to be taken into account. For that reason, as explained in Section 4.2 a parallel land evaluation procedure is convenient because it relies on commensuration in economic (monetary) terms being done at the same time as the physical analysis that defines the values of criterion variables in physical terms.

In semi-detailed and reconnaissance type land evaluations, simpler and less quantitative methods prevail; therefore the multi-dimensional status of the Criterion Function in the definitions of the land suitability classes is maintained (see Table 5.3).

Table 5.3 The presentation of a multi-dimensional physical land suitability classification

land mapping units (LU)	land utilization types							
	LUT - 1				LUT - 2			
	criterion variables			Suitability class	criterion variables			Suitability class
	inputs	outputs	land qualities	$C=F(c_1..c_n)$	inputs	outputs	land qualities	$C=F(c_1..c_n)$
	$c_1,..$	$c_2,..$	c_n		$c_1,..$	$c_2,..$	c_n	
LU-1	1	1	2	C=I	2	2	2	C=II
LU-2	2	3	4	C=IV	3	2	3	C=III

5.4.1 Descriptive input-output analysis

Analysis of input-output relations is normally undertaken by economists and farm management specialists who base their analysis on a variety of mathematical and statistical techniques, e.g principal component analysis, production functions, and linear programming (Heady and Dillon, 1961; Heady, 1957; Dillon, 1968; Heady and Candler, 1958; Found, 1971; Mullers, 1977; Bofinger and Wheeler, Eds, 1975). Some of these methods include agricultural production functions that take into account a great many different variables ranging from physical factors such as climate, soil, water, to socio-economic variables such as management, education or the budget reserved for agronomic research (Hedges, 1963; Barlowe, 1972).

In land evaluation one is not concerned with such complex models of input-output analysis. On the contrary, land evaluation in its deductive stage avoids possible conflicts arising from incompletely understood relationships and interactions between the multiple factors involved. Complex agricultural production functions can be successfully applied in the light of sufficient real information, as may be available for *post facto* analysis of agricultural experiments or of present land use based on detailed farm surveys. But land evaluation primarily serves predictive purposes and is likely to be confronted with situations where there is insufficient real information available for applying such complex methods.

To avoid confusion with the economic type of input-output analysis it is perhaps better to speak of 'intermediate' input-output analysis. Within the range of input possibilities of the land utilization type in question (or of the land improvement project when major improvements are included, beyond the possibilities of individual utilization types) we select a number of relevant physical input levels and for each of them the effect on the outputs and on the land qualities is described.

The soil series described in the USA using the Soil Taxonomy (USDA, 1976) are expected to be sufficiently homogeneous to permit transfer of experimental results from so-called 'Benchmark' (representative) sites to other sites with soils of the same series which have not been studied directly. Such Benchmark soils are analogue models serving the purpose of extrapolation of experimental results (Dijkerman, 1974).

The use of systems analysis and simulation models may modify the data collecting stage in land evaluation, the methods and density of sampling (Bouma, 1977), the techniques of making land resources maps and the classification of land attributes, e.g. the application of a numerical soil classification (De Gruyter, 1977).

An important advantage of using mathematical simulation models, when comparing them with the real systems, is that they can be operated in two directions: the role of the dependent variables (the outputs and the land qualities that need to be improved with inputs) and the independent variables (the inputs) can be interchanged. When the output is known first, the questions posed to land evaluation will refer to matters such as where,when and how to produce: which type of land to choose; cropping calendar; kind and amounts of inputs to be applied, input application method.

The possibility of interchanging variables in mathematical systems is also important when the values of certain land qualities have been fixed beforehand: the conservation of a particular rare plant or animal species at a specified density, the preservation of a particular quality of the landscape such as concealing ugly buildings by maintaining a cordon of trees around building sites. In this case the land qualities are to be handled as independent constraints within a defined range, while both outputs and inputs become dependent variables, when analysing the input-land quality relations and the land quality-output relations.

Land qualities can be output variables when specific questions are asked about their status; e.g. the workability of the soil that results from different soil loosening processes in an evaluation of different soil tillage methods (Koolen, 1977). Yield may be considered both an output variable and a 'super' land quality (see Section 3.1.1). In the latter case yield becomes a state variable, e.g.the yield of grass in a grazing system.

Descriptive input-output analysis is not concerned with optimizing input-output relations. It consists of a number of simulations of the real land use processes for different kinds of input and different input levels to determine the corresponding outputs (or vice versa) and the status of the land qualities, that are responsible for the continuity of the land use process.

Strictly speaking the inputs added to the land use system in each simulation influence the system in a manner comparable to that of the uncontrollable land qualities, such as radiation and temperature. During the separate input-output simulations it does not become apparent that the input levels have been rationally chosen in view of subsequent prescriptive input-output analysis. Only when the results of two or more simulations are compared against the background of specific land suitability criteria, will the inputs represent decision variables in the true sense: prescriptive systems analysis.

The role of land qualities and land requirements

Descriptive analysis of input-output relations emphasizes the role of land qualities. The reasons are:

- Outputs may differ on different land units when no inputs are applied for land improvement, because of differences in the unimproved status of the land qualities (LQ_u).
- The status that the land conditions are expected to assume at different input levels and described in terms of land qualities after improvement (LQ_i) represent important information for land suitability classification and land use planning.

- The response to inputs (crop response) on different land units when applying the same type and amount of input with the same method may differ because of differences between these land units in land properties and qualities influencing this responsiveness to inputs.

Input-output analysis should include in the first place the study of the relation between land qualities and the outputs, and the relation between inputs and outputs. These two relations and the input-land quality relations together represent the relation structure of the land use system:

land quality-output relations	(1)
input-output relations	(2)
input-land quality relations	(3)

The land qualities seem to have several roles during the input-output analysis: they act as independent variables in the analysis of land quality-output relations and as dependent variables in the analysis of input-land quality-relations. In the analysis of input-output relations they are like intermediate variables, serving the purpose of grouping the multitude of different land (mapping) units into populations or 'classes' with similar levels of land qualities and properties as far as input-output relations are concerned (Beek, 1977).

In a problem-oriented land evaluation the input-output analysis should be based on knowledge of the land qualities that are limiting, i.e. that require inputs for their improvement. Techniques for identifying limiting land qualities and for quantifying their influence on the input-output relations vary from direct observation of natural phenomena such as the interpretation of mineral deficiencies and toxicities from plant features, to analyses of the results of controlled experiments. Comparison of different values of a land quality (of which the limiting effect is assessed) with corresponding output values should permit expression of the LQ-Y relation for that particular land quality, which will depend on the requirements LR of the land utilization type for the land quality in question (see also Section 3.2).

Productivity ratings can provide a useful check on the weights attributed to the land qualities that condition productivity. Physical land evaluation should pay great attention to the estimation of productivity levels, which according to Beek and Bennema (1972) may follow five different procedures:

- direct measurement of site-specific yields
- analysis of site-specific statistical data on productivity
- site-specific empiricism, by establishing correlations between measured yields and the relevant land qualities or between measured yield and the land (mapping) unit as a whole (e.g. Van Goor, 1965/66)
- site-specific empiricism, by establishing correlations between measured yields and single characteristics of the land, such as soil depth and soil texture (e.g. Riquier, Bramao and Cornet, 1970; Sys, FAO 1975; see also Section 3.1.2)
- land use simulation models, based on fundamental plant growth and production processes, which may include land qualities and/or properties in their equations for calculating theoretical yields (e.g. De Wit *et al.* 1971, 1978).

Study of the land requirements of specific land utilization types in view of the types of crops grown, the type of equipment used and of other attributes and management techniques, is more a concern for agronomic research than for land evaluation as such. But land evaluation can formulate some key questions to be answered by agronomic research on the values of LR. The functional explanations that can relate the values of LR to measurable characteristics of the crop/equipment/utilization type that determine these requirements are very interesting. Examples of these functional characteristics are: the leaf area index (LAI) and the stomatal characteristics that control the potential evapotranspiration; rooting system characteristics that control the uptake of water and nutrients (see Section 3.2 for more reference to the study of LR); the specifications of power, bearing pressure and operational depth of farm equipment that control the requirements for workable land conditions.

For land utilization types that depend entirely on the natural status of the land, a land suitability classification could be based exclusively on information about the land requirements (LR) and on land quality-output relations. Examples are the land suitability classifications applied in forestry (van Goor, 1965/1966) and the land suitability classification for 'traditional' agriculture in Brazil (Section 5.3.4). In the latter system the relationship between the land quality, 'natural fertility' and output has been expressed in terms of yield, expected period that these yields can be maintained and subsequent trends in yield decline.

But in most cases land evaluation includes the consideration of land use systems that can make use of physical inputs to reduce the problems caused by limiting land qualities. The (LQ,Y) combinations identified during land quality-output analysis can indicate the probability of response to specific physical inputs. The response probability depends on whether the value found for the land quality of a land unit is situated below or above the value at which no further increase in yield of a specific crop is to be expected from higher values of LQ: the critical value or 'critical level', and on the difference between the critical value and the present value of the land quality in question.

An interesting contribution to the discussion on interacting *versus* most limiting factors in biological production processes is the 'linear response and plateau model' of Waugh *et al.* (1973, 1975). In soil fertility evaluation it has been observed that in most cases fertilizer response curves consist of two trajects: a sharp linear increase followed by a flat horizontal line (Bartholomew, 1972; Boyd, 1970, 1974; cited in Sanchez, 1976). On the strength of this observation and on the many experiments with fertilizers and soil fertility tests of the North Carolina Soil Testing Program, and by FAO, Waugh *et al.* developed a discontinuous input-output function (see Fig. 5.6.) that consists of two lines: the first line represents the relatively steep response of an added nutrient until it ceases to be a limiting factor. The second line is a horizontal 'plateau', when further additions of the nutrient in question no longer increase yield. The fertilizer rate needed to reach the 'plateau' yield should be the recommended rate for the nutrient. This plateau yield is not necessarily the maximum yield because other nutrients may still be limiting the yield at the site of the fertilizer experiment.

Land qualities other than soil fertility have not been considered, but they could become the most limiting factors when the soil fertility problem can be solved. The final plateau yield is determined by genetic characteristics of the crop (variety) and the uncontrollable variables of the land unit e.g. the land reclamation level (the boundary between controllable and uncontrollable should greatly depend on the abilities of the land utilization type to manage, improve and conserve the land conditions).

The promising results in soil fertility research, are encouraging for the use of conversion tables in land evaluation in relating outputs or land suitability classes to defined levels of land qualities.

The simplified diagram presented in Fig. 5.6 summarizes the result of statistical studies of input-output relations when selected plant nutrients limit crop production. This method of Waugh *et al.* is supported by the simple technique used by Cate and Nelson (1965, 1971) to identify the critical level of soil test values to separate soils with a low probability of response to fertilizers from soils with a high probability of response (Fig.5.7). This critical level is identified by taking a transparant overlay sheet divided into quadrants by vertical and horizontal lines, and superimposing it on the scattered data points expressing the (LQ, Y) relation between the element in question and relative yield (% of maximum attainable at the site). The overlay is manipulated until the fewest points are left in the upper left and lower right quadrants. The critical soil test level is the point at which the vertical line intersects with the x-axis, dividing the data points with a larger yield response probability from those with a low response probability. Other studies by the same authors include proposals for statistical methods to partition soil test crop response probability in more than two classes (Cate and Nelson, 1971; Nelson and Anderson, 1977).

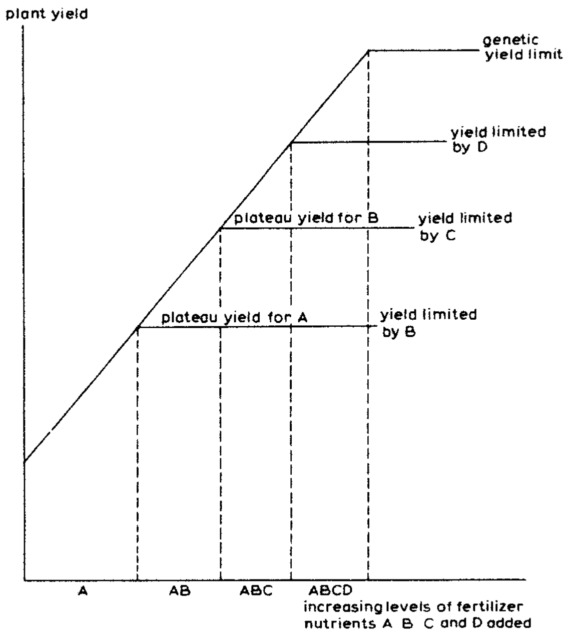

Fig.5.6: Linear response and plateau (LRP) model, based on Liebig's law of the minimum. Source: Waugh et al.(1973).

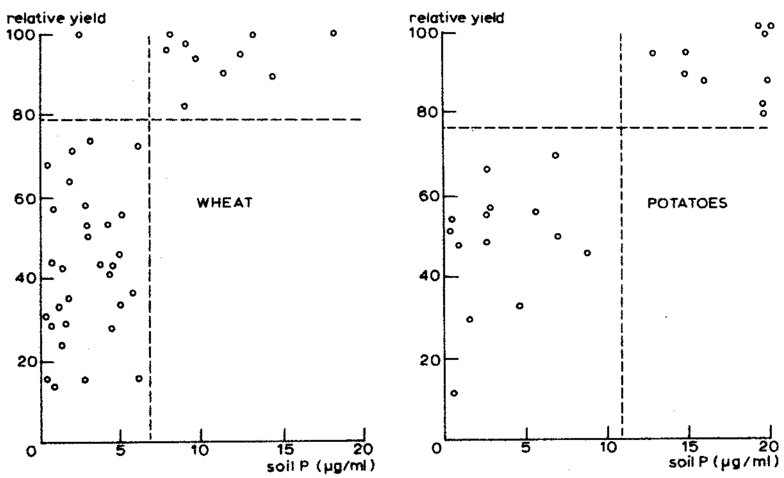

Fig.5.7: Scatter diagram of percentage yield (of wheat and potatoes) versus soil P-test by 0,5 M $NaHCO_3$ (1/13) according to Cate-Nelson method. (From experimental results by Ministry of Agriculture, Bolivia, in cooperation with International Soil Fertility Evaluation Project, USAID North Carolina State University). Source: Waugh et al., 1973.

The interpretation of fertilizer response curves as two straight lines is to simplify soil test and fertilizer experiment interpretations. The authors of the method do not dispute that the actual input-output function is continuous and curvilinear, but want to keep the data analysis as simple as possible. The question arises how far simplification may go. Can certain phenomena of interaction and cumulative effects between plant growth factors be ignored for the sake of simplification? The linear response and plateau model encourages, at least in soil fertility evaluation, the construction of conversion tables that emphasize the importance of the most limiting factor while paying less attention to the interactions between the limiting factors and their cumulative effects. Comparative regression studies have indicated that the linear response and plateau model provides as good results as the more conventional continuous curvilinear functions. But when attempting to apply the general principles of their observations (which are stated to be in line with Liebig's law of the minimum)[1] to land evaluation in general we are confronted with several questions:

In the first place the slope of the function of Fig. 5.6 is not necessarily the same for each limiting nutrient. But that could probably be remedied by mathematical manipulation of the scale of the x-axis. A more serious problem concerns the interaction between nutrients at higher levels of productivity. Nitrogen is likely to be needed in higher amounts at higher levels of productivity and the same is probably true for potassium. Nitrogen and potassium are removed in relatively high quantities from the soil compared with phosphorus, which also has a greater residual effect than the other nutrients. The existence of a critical soil phosphorus level seems therefore to have more prospects for practical land evaluation than that of a potassium or nitrogen level, the supply of which should be correlated in the first place with the requirements of the crop in question.

Generally speaking the statistical correlations found between inputs and outputs should be complemented by functional explanations

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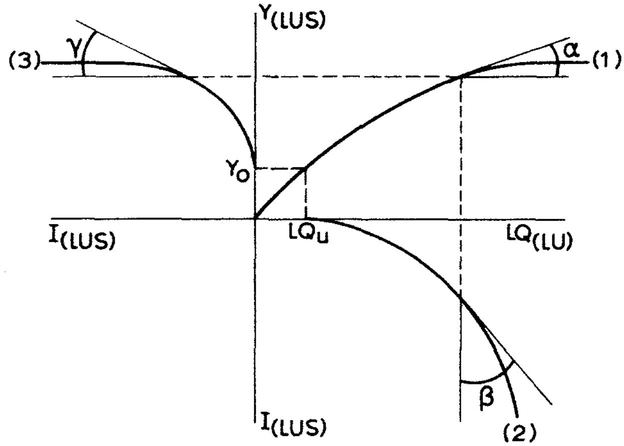
[1] *Liebig's law of the minimum establishes that the productivity level is determined by the most limiting factor.*

that take account of factual land use processes. For example in Brazil (Köster *et al.,* 1977) a five to ten times increase of productivity of degraded *Panicum maximum* pastures has been reported, after applying 60 kg/ha of P205 to very poor Amazon oxisols with less than 1 ppm P in the top 5 cm. According to De Wit and Van Keulen (personal communication, 1978) an explanation for this response should take into account the possible effect of the phosphorous fertilizers (triple superphosphate) on the micro-biological processes of nitrogen fixation and mineralization. Since crops (varieties) and land utilization types differ greatly in their land requirements and in their (genetic) capacity to respond to physical inputs, conversion tables must be LUT-specific. It has now been established that traditional, local, varieties, primarily chosen to secure a safe minimum food supply, are more resistant to climatic and biotic hazards than are recently developed higher yielding varieties, which have been selected primarily to respond well to physical inputs such as fertilizers and irrigation water.

Descriptive input-output analysis and relation structure: a synthesis

In Fig.5.8 the three fundamental relations that make up the relation structure of a land use system analysed for purposes of land evaluation have been presented graphically: in Graph (1) the relationship between output and the land quality level is given. Graph (2) gives the relation between the land quality level and the amount of input applied for the improvement of this land quality (assuming that other land qualities are less limiting). In Graph (3) the relationship between output and amount of input application is indicated.

Differences between types of inputs and between methods of input application may result in different Graphs (2) and (3). Land units with different land improvement qualities are also likely to show different Graphs (2) and (3). Land utilization types that are different in their requirements for the land quality in question can be expected to show differences in Graphs (1) and (3). The three Graphs (1), (2), and (3) are interrelated: one Graph can be constructed from the two others through the elimination of one variable. In land evaluation the land quality variable will mostly be the intermediate variable that is eliminated: Graph (3) is constructed from Graphs (1) and (2).



$Y_{(LUS)}$ = output of specific LUT, LU combination
$LQ_{(LU)}$ = most constraining land quality of LU
$I_{(LUS)}$ = input for improving LQ, with specified application method
$LQ_{u(LU)}$ = level of constraining land quality LQ before inputs have been applied
Y_o = output at zero level of input (threshold output)
tang α = slope of Y = F (LQ), determined by land requirement LR of LUT for LQ
tang β = slope of LQ = F (I), determined by improvement quality IQ of LU and input application method
tang γ = slope of Y = F (I), determined by LR, IQ and input application method

Fig.5.8: Co-axial analysis of input-land quality-output relations.

Graphical expression of the relation structure of a land use system therefore would require knowledge for the fitting of at least two curves. Such a method may be convenient for the interpretation of the results of controlled experiments[1], but in land evaluation it will often be difficult to make use of precisely measurable uptake values.

Measuring land properties and qualities for several reasons (e.g. variance of values of variables within land mapping units; temporal variance; limits posed to measurement techniques and to data interpretation) has often been in terms of ranges of values, expressed either on an ordinal or a ratio scale: soil salinity classes, drainage classes, workability classes, erosion hazard classes etc., rather than in absolute, fixed values.

The selection of input values for the field experimentation underlying input-output analysis also uses ranges, for convenience' sake, subdividing the continuum of input levels into a few levels, e.g.: 0-30-60 kg fertilizers (pure nutrients) per hectare; 0-10-20-30-40 metres subsurface drain spacings.

As a consequence, the relations between inputs and land qualities, between inputs and outputs or between land qualities and outputs are also necessarily based on these selected ranges and levels.

The users of such analyses will usually accept these simplifications, which may result in output also being expressed in ranges of values, rather than in absolute values. The user thus accepts the limitations imposed on a more precise, but not necessarily more accurate, result of land evaluation. Against this background a tabular presentation of the relation structure of land use systems provides a convenient and simple alternative for the use of continuous functions and co-axial analysis: in Table 5.4 a combination of two conversion tables is shown in which the most constraining land quality LQ_p plays the role of intermediate variable in input-output analysis. Interactions between different constraining land qualities can also be taken into account as will be shown later (LQ_p versus LQ_d).

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1 *e.g. De Wit (1953) and Van Keulen (1977) have applied co-axial analysis successfully for the interpretation of fertilizer experiments, using nutrient uptake as an intermediate variable between input and output. The uptake rate can be measured and expressed on a continuous ratio scale.*

Table 5.4A is the 'land quality table', which expresses the input-land quality relations of three land units with different land improvement qualities IQ and seven selected input levels $I_0 - I_1 - \ldots I_6$. For different input application methods different land quality tables may result.

Table 5.4B is the 'output table' which expresses the land quality - output relations of two land utilization types with different requirements (LR) for land quality LQ_p, also considered in Table 5.4A.

Combination of tables A and B permits the identification of alternative input-output combinations for each (LUT, LU) combination or LUS. Tables A and B can also be used to identify the specific input level that is required to achieve a given output level or vice versa. For example the following yields have been estimated without taking into consideration the constraining land quality LQ_p:

$$Y_{(LUT\ 1,\ LU\ 1)} = 3000 \text{ kg/ha}$$
$$Y_{(LUT\ 1,\ LU\ 2)} = 4000 \text{ kg/ha}$$
$$Y_{(LUT\ 1,\ LU\ 3)} = 5000 \text{ kg/ha}$$
$$Y_{(LUT\ 2,\ LU\ 1)} = 3000 \text{ kg/ha}$$
$$Y_{(LUT\ 2,\ LU\ 2)} = 4000 \text{ kg/ha}$$
$$Y_{(LUT\ 2,\ LU\ 3)} = 5000 \text{ kg/ha}$$

Table 5.4: Tabular analysis of input - land quality - output relations

A: Land Quality Table

INPUT LEVELS	Land Quality Rating, LQ_p		
	LU-1 with $LQ_{p1,d1,t1}$ and IQ_1	LU-2 with $LQ_{p2,d2,t2}$ and IQ_2	LU-3 with $LQ_{p2,d3,t2}$ and IQ_3
I 0	10	15	15
I 1	15	25	30
I 2	20	35	45
I 3	25	45	60
I 4	30	55	75
I 5	35	65	90
I 6	40	75	90

LQ_p = *available nitrogen in soil*
LQ_d = *available oxygen in soil*
LQ_t = *soil temperature*
IQ = *land improvement quality available nitrogen*
I = *inputs of nitrogenous fertilizer*

B: Output Table

LAND QUALITY LEVELS OF LQ_p	Output Rating, Y	
	LUT-1 with LR 1	LUT-2 with LR 2
5	0	0
15	2000	500
25	4000	1500
35	6000	2500
45	6000	3500
55	6000	4500
65	5500	5000
75	5000	5000

LR = *land requirement for LQ_p (nitrogen)*

Based on Tables 5.4A and 5.4B the following input levels I (with specified application method) can be calculated:

Table 5.5: Calculation of input levels I

	LUT 1			LUT 2		
	Y ⟶	LQ_p ⟶	I	Y ⟶	LQ_p ⟶	I
		(Table B)	(Table A)		(Table B)	(Table A)
LU 1	30 000	20	2	3 000	40	6
LU 2	4 000	25	1	4 000	50	4
LU 3	5 000	30	1	5 000	60	3

Interacting land qualities: Suppose that LQ_p represents the land quality 'available nitrogen' (the nitrogen sub-system) and LQ_d represents the land quality 'available oxygen', strongly influenced by the drainage conditions. If land unit LU 1, which is characterized by poor drainage conditions and therefore by a poor response to nitrogen fertilizers (low IQ), can be improved by major drainage works, the land quality LQ_d may be raised from LQ_{d1} to LQ_{d3}, thus becoming similar to land unit LU 3, also in its response to fertilizer. Consequently input levels for improving LQ_p of LU 1 now correspond with the input levels given for LU 3 in land quality Table 5.4A.

Constraints on the inputs, outputs and land qualities

The consideration of constraints is a first step towards prescriptive systems analysis, but in addition, during the descriptive input-output analysis the input/land quality/output combinations that are presented must take into account the existing constraints. Therefore sets of (I, LQ, Y) values should be presented that exclude values within the forbidden trajects of the I, LQ and Y axes. Examples are Fig.5.9 and Table 5.6 which have been based on Fig.5.8 and Table 5.4.

In any case, descriptive and prescriptive analysis are closely related.

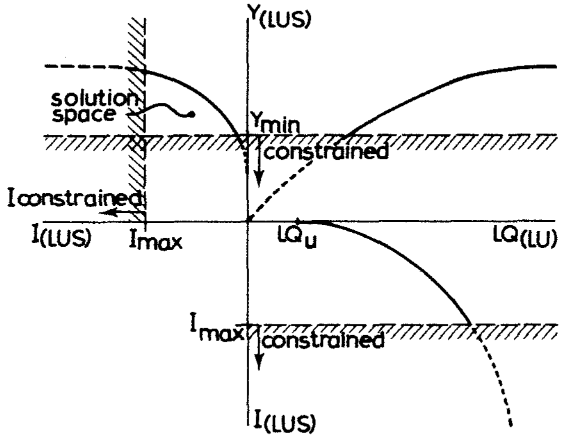

Fig.5.9: Co-axial input-output analysis with limited solution space due to constraints on inputs (I_{max}) and outputs (Y_{min}).

The role of constraints on inputs, outputs and land qualities can conveniently be discussed against the background of Fig.5.10.

The analysis of input-output relations should take into account which input levels of a certain type and application method are pertinent for the land utilization type in question and for the development situation in general. This means that on the I-axis of a graph expressing input-output relations only the traject of the pertinent input application rates should be taken into account. Suppose that the input-output analysis in Fig.5.10 is concerned with two types of land utilization for growing cotton: one type that is not constrained in the level of phosphatic fertilizers (type I); and another, type II, that is constrained by an upper limit of I_x units, an amount that depends on the market price of fertilizer and the farmer's access to credit.

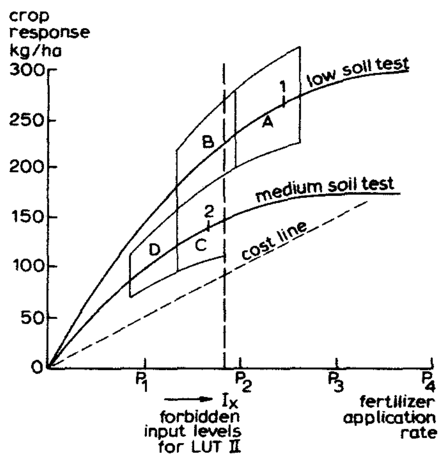

Fig.5.10: Input-output analysis with a constrained input level (I_x). Source: Adapted from Hauser, 1973.

According to the slope of the costline[1] points 1 and 2 on the regression lines indicate the optimal (I,Y) combinations for land units with low and medium P soil test values respectively. Often a range of (I,Y) values is preferred above a fixed value, because of the expected variance in response to inputs. The optimum ranges have been indicated by A for the low P soil test regression line and C for the medium P soil test regression line.

Taking into account the constraint on inputs for land utilization type II, as indicated by I_x, the land mapping units with medium P-test could still receive the optimal fertilizer rate, while the low P-test land units should receive amounts well below the optimum. But as Hauser explains (1973) lower than optimal doses of fertilizer are sometimes convenient when benefit/cost ratios are more important than benefits per hectare. For the ranges B and D with steeper slopes than the ranges A and C the benefit/cost ratio is higher, while the benefit per hectare is lower because of a lower productivity.

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1 *The line that connects points (I, Y) for which the marginal cost equals marginal benefit, or some other cost benefit criterion, e.g. marginal cost equals half the marginal benefit.*

Table 5.6: Descriptive input-output table (based on Table 5.4) with constraints I_{max} LUT-1 = 1; I_{max} LUT-2 = 3; Y_{min} LUT-1 = 2000; Y_{min} LUT-2 = 1000. (Irrelevant I-Y combinations have been excluded)

	I	Y		
		LU-1	LU-2	LU-3
LUT-1	0	-	2000	2000
	1	2000	4000	± 5000
LUT-2	0	-	-	-
	1	-	1500	± 2000
	2	± 1000	2500	3500
	3	1500	3500	± 4750

Low income farmers in developing countries, where the cost of fertilizers may represent a high percentage of the total capital input, are often more interested in high monetary returns to be able to repay their loans (I,Y combinations corresponding with ranges B and D) than in highest profits (ranges A and C). Therefore input-output analysis should envisage the description of input-output relations at various input and output levels and not aim exclusively at identifying the highest profit combination. 'Constraints' on the inputs (input restrictions) may stem from different causes, as reflected by the attributes and abilities of the land utilization types in question. Well known are available capital and credit, risk-taking capacity and available labour. The kind of equipment and the local availability of physical inputs (e.g. fertilizers, irrigation water) should also be taken into account.

Constraints sometimes also affect the land qualities and the outputs. Constraints on land qualities often originate from environmental criteria, e.g. that the groundwater should remain at a certain level to preserve valuable drought-susceptible plant species. Another example is the need to control the calcium level of the soil to avoid the spread of soil-borne pests and diseases.

Outputs are sometimes constrained in the sense that their values, e.g.

yield, have been calculated beforehand, in which case it will be the task of land evaluation to find the corresponding inputs. Fig.5.10 and Table 5.6 are examples of a constraint on the output (Y_{min}) determined by the minimum food requirements of a (subsistence) farm family.

Summarizing:

Descriptive input-output analysis in specific purpose land evaluation should be based on three relations of a specific land use system (specific LU, LUT combination) which together make up its relation structure. These relations are:

- the land quality-output relations
- the input-output relations
- the input-land quality relations

For this purpose the land (mapping) units need to be grouped in such a way, that the response to inputs, as conditioned by the unimproved levels of constraining land qualities (LQ_p),the levels of other influential land qualities (LQ) and the values expressing the land improvement qualities (IQ) of these land mapping units, as measured during specified time period Δt, are similar for each group. The input-output relations also depend on the parametric values expressing the land requirements (LR) of each land utilization type during Δt. Possible constraints on the levels of inputs, land qualities and outputs should also be taken into account:

$$Y_{(LUS)} = F\ (LQ_{p\ \text{unimproved}\ (LU)},\ I_{(LUS)},\ IQ_{(LU)},\ LQ_{d,t(LU)},\ LR_{(LUT)}) \quad (1)$$

$$\text{since}\ LQ_{p\ \text{improved}\ (LU)} = F\ (LQ_{p\ \text{unimproved}},\ I_{(LUS)},\ IQ_{(LU)} \quad (2)$$

$$Y_{(LUS)} = F\ (LQ_{p\ \text{improved}\ (LU)},\ LQ_{d,t\ (LU)},\ LR_{(LUT)} \quad (3)$$

I_{max} = *a (constraint on inputs)*
I_{min} = *b (constraint on outputs)*
$LQ_{t\ min}$ = *c (constraint on land quality)*

(For explanation of symbols see text and Figs. 5.8 and 5.10, where equations (1), (2) and (3) have been presented graphically and Table 5.4 where equations (2) and (3) have been presented in tabular form.)

Input-output relations are use-specific and environment-specific, because of the many site characteristics involved. Often they are also time-specific due to the dynamic character of the land use system. Therefore input-output analysis must be based on real information observed and measured directly at defined time periods in the field or from samples taken to the laboratory. Since such measurements are by definition, limited, maximum use should be made of the information provided by land resources inventories in the selection of representative observation sites for extrapolation of the conclusions. Indeed, this is already being done in water management, soil conservation and agricultural engineering, albeit not always with the desired results, considering the abundance of irrigation projects with severe soil salinization problems. But in the analysis of soil fertility problems, at least in the Americas, soil survey and soil fertility research, according to Buol *et al.*,(1975, pp.126-141 in E. Bornemisza and A. Alvarado, Eds.), have played rather separate and sometimes even 'competitive' roles in the evaluation of the agricultural potential. Sanchez (1976 p. 355) concludes that

> efforts must be increased to bring soil survey data into soil fertility evaluation projects ... The development of technical classification systems grouping soils with similar fertility limitations is likely to improve the effectiveness of soil fertility evaluation programmes and to bridge the present gap between the two disciplines.

5.4.2 Prescriptive land suitability classification

At the beginning of Section 5.4 has been described how the definitions of land suitability classes are specified against the background of explicit land use objectives and translated into land suitability criteria. Once these classes are described it should become possible to determine the land suitability class for each (LUT,LU) combination by critically comparing these class definitions with the values taken by the criterion variables.

But a land suitability classification process in specific purpose land evaluation is likely to comprise more than just the specification of suitability class definitions and the determination of suitability classes for different (LUT,LU) combinations. The reason is that its aim is not limited to classifying the suitability of the land for specified purposes but also to ensure that these purposes are the most relevant development alternatives for the area in question, given the prevailing physical land constraints. Only during the prescriptive land suitability classification will it be possible to appreciate fully how serious these constraints are for the land utilization types selected at the beginning of land evaluation. As a consequence it may happen that these definitions, synthesized at an earlier stage, are no longer satisfactory, if the discrepancies observed between their land requirements (LR) and the qualities of the land (even after improvements with all kinds of inputs), remain too great, resulting in too low land suitability classes. It may also happen that all land units are classified as equally suitable or that no land unit can be found that meets the land suitability criteria for the use in question, making an unsatisfactory base for land use planning decisions.

To solve this problem it may be necessary to adapt the (LUT,LU) combination, not by adapting the LU with variable inputs to the requirements of the LUT, but by adjusting the LUT and its requirements for land in the light of the accumulated knowledge about the constraining influence of the land units on the performance of the land use system. The changes made during this adjustment, e.g. the selection of another type of equipment or management technique or of a different crop variety with land requirements better adapted to the limiting land qualities, also make it necessary to revise the descriptive input-output analysis. After this, the land suitability classification can be repeated to ascertain if a more satisfactory grouping of land units has been achieved.

In physical land evaluation the 'adjustment' of land utilization types will mostly be qualitative, depending on the scale, the kind and number of land suitability criteria, the availability of data and the participation of specialists of the agronomic and socio-economic discipline. Its results are processed as a corrective feedback to revise the earlier defined land utilization types. Modifications will refer principally to physical aspects: the type of crops and varieties, the type of implements, the rotation scheme. Such refined definitions represent only an intermediate or 'sub-optimal' result in the process of selecting optimal land use systems. The latter requires quantitative methods of economic analysis such as linear and dynamic programming as explained during the discussion on integral land evaluation (Section 4.2.2).

If the land suitability classification and the adjustment of the land utilization type definitions still do not produce satisfactory results, there is another possibility for reconciling (LUT,LU) systems and land suitability criteria: by adjusting the land suitability criteria themselves, e.g. a check of the possibility of accepting a lower yield or a higher erosion loss from a particular land suitability class.Adjustment of land suitability criteria can have far-reaching consequences and therefore requires considerable consultation with the decision-makers.

It may be concluded that prescriptive land suitability classification in specific purpose land evaluation offers considerable flexibility to the land evaluating team for reconciling (LUT,LU) system variables and land suitability criteria.

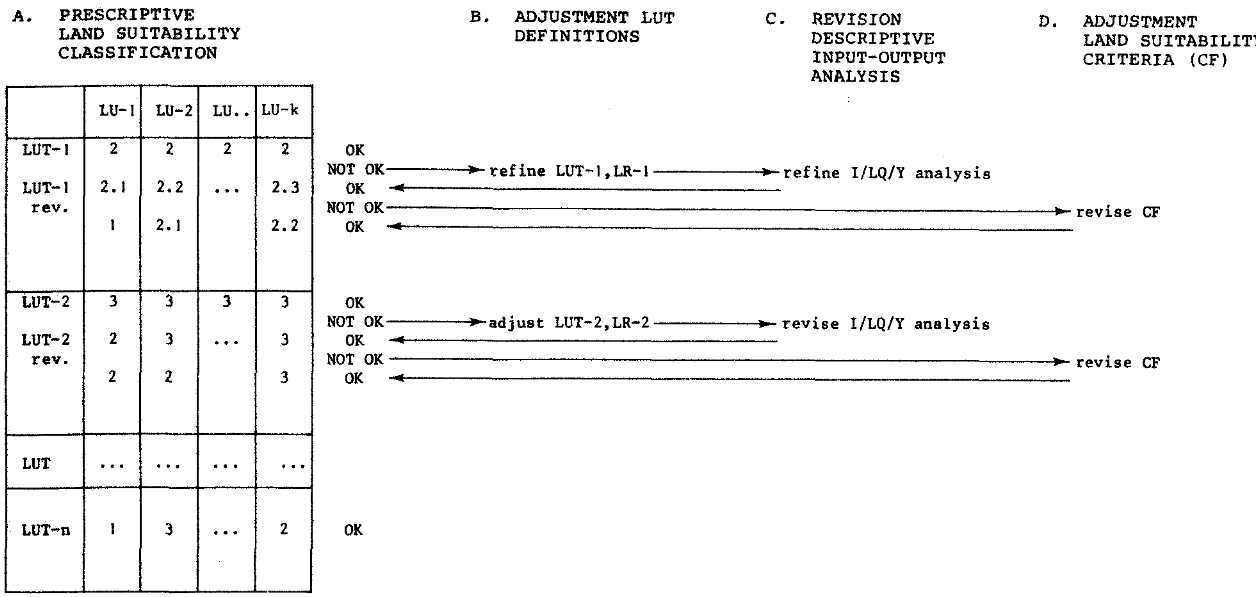
Matching

It is proposed to adopt the term 'matching' to describe a comprehensive process of land suitability classification as referred to above, which not only specifies land suitability class definitions and determines land suitability classes for different (LUT,LU) combinations, but also offers the possibility of adjusting the definitions of land utilization types and of the Criterion Function (see Fig.5.4). A land classification system that includes matching therefore has a much wider scope than one that is solely interested in determining land suitability classes for pre-established land utilization types, against the background of fixed land suitability criteria (which in the past have seldom been clearly defined anyway). The term 'matching' was introduced originally (Beek, in FAO, 1975a) solely to describe the process of adjusting the definitions of land utilization types during prescriptive land suitability classification. It has been adopted with the same meaning in the *Framework for Land Evaluation* (FAO, 1976). However it seems justified to expand its meaning to embrace all the activities taking place during the prescriptive land suitability classification process because of the many linkages between them:

- the specification of definitions of land suitability classes
- the determination of land suitability classes for different (LUT,LU) combinations
- the adjustment of land utilization type definitions
- the adjustment of the Criterion Function and consequently of the definitions of the land suitability classes

Of course it will not always be necessary to carry out all the activities listed above. The definitions of land suitability classes in particular will often be standardized.

Matching represents the essence of a multi-disciplinary approach to specific purpose land evaluation, which aims simultaneously at the classification of land suitability and the selection of the most relevant land utilization types (see Fig.5.11).



	LU-1	LU-2	LU..	LU-k
LUT-1	2	2	2	2
LUT-1 rev.	2.1	2.2	...	2.3
	1	2.1		2.2
LUT-2	3	3	3	3
LUT-2 rev.	2	3	...	3
	2	2		3
LUT	...	...	...	...
LUT-n	1	3	...	2

1 = *highly suitable*
2 = *suitable*
3 = *not suitable*

Fig.5.11: The matching process. An example.

Conversion tables

An example of how reconnaissance type land suitability classes can be conveniently expressed in terms of physical values of criterion variables to guide matching is the conversion tables for specific land utilization types applied in the Brazilian land suitability classification systems (Section 4.3.4. Appendix 2; Bennema, Beek and Camargo, 1964). These tables relate specified values of selected land qualities and inputs directly with land suitability classes. Selected land qualities include natural soil fertility, available water, excess water (distinguishing between drainage and flooding hazards), susceptibility to erosion and possibilities for the use of mechanical implements. Each land quality has been defined at several levels of quality, varying from four to seven levels. Different land qualities have been considered for different land utilization types, e.g. agricultural, grazing and forestry types.

It will sometimes be possible to make a reliable estimate of the expected yield per hectare of land units for a particular land utilization type. In this case the yield (an output variable) may become a criterion variable for the land suitability classification. It may thus replace those land qualities in the conversion table that were chosen for their influence on the output. Tables 5.7 and 5.8 are examples of conversion tables with and without yields as criterion variables.

The construction of conversion tables is a multi-disciplinary task, which requires a good understanding of the structure of the land use system that is envisaged, and therefore of the relations between its inputs, land qualities and outputs (see Section 5.4.1). Values of I, LQ and Y need to be identified, corresponding with each land suitability class.

Table 5.9 is an example of the conversion of criterion variables into suitability classes based on different levels of inputs of fertilizers (I_F), erosion control measures (I_E) and corresponding outputs expressed in levels of yields (Y_1) and erosion losses (Y_2). Since the criterion variables I, I_E, Y_1 and Y_2 have been expressed in levels and ranges, the

Table 5.7 Conversion table for land suitability classification, with criterion variable 'expected yield'

	Suitability classes				
	I high	II medium		III restricted	IV low
DRY FARMING					
Freedom to select size and shape of fields	1	1		2	any grade of the qualities lower than for restricted
Resistance erosion	1A	1A		2A	
Adaptability mechanization	1A	1A		2A	
Expected yields of wheat	3A	4A		4A	
IRRIGATED AGRICULTURE					
Freedom to select size and shape of fields	1C	1	2	2	any grade of the qualities lower than for restricted
Resistance erosion	1D	1	1	1	
Adaptability Mechanization	1C	1	1	2	
Expected yields of wheat	1C	1D	2C	2D	

input levels	land quality levels
A = low	*1 = high*
B = medium	*2 = medium*
C = high	*3 = low*
D = very high	*4 = very low*

Source: Beek & Bennema (1972)

Table 5.8 Conversion table for land suitability classification, with criterion variable expected yield'

	Suitability classes				
	I high	II medium		III restricted	IV low
DRY FARMING					
Freedom lay-out of the scheme	1	1	1	2	
Resistance erosion	1A	1A	1A	2A	any grade of the qualities
Adaptability mechanization	1A	1A	1A	2A	lower than for restricted or
Availability oxygen	2	3	2	3	any of the im- provements in-
Absence risk salinization	1	3	2	3	puts higher than for restricted
Availability water	3	3	4	4	
Availability nutrients	1A	1A		2A	
IRRIGATED AGRICULTURE					
Freedom lay-out of the scheme	1	1	2	2	any grade of
Resistance erosion	1	1	1	1	the qualities
Adaptability mechanization	1	1	1	2	lower than for restricted or
Availability oxygen	1	2	2	3	any of the im-
Absence risk salinization	1	1	2	2	provements in-
Availability water	1C	1D	1C	2D	puts higher than for restricted
Availability nutrients	1B	1B		1B	

input levels	land quality levels
A = low	*1 = high*
B = medium	*2 = medium*
C = high	*3 = low*
D = very high	*4 = very low*

Source: Beek & Bennema (1972)

deductive part of the physical land evaluation becomes relatively easy: there is no need to express the input-output relations in terms of continuous functions to permit the identification of the optimal values of I and Y on a ratio scale. It should suffice to correlate the LU, LUT combinations according to their sets of (I, Y) values with the squares indicated in Table 5.9 and select for each (group of) land unit(s) the square of highest possible suitability class for the land utilization type in question.

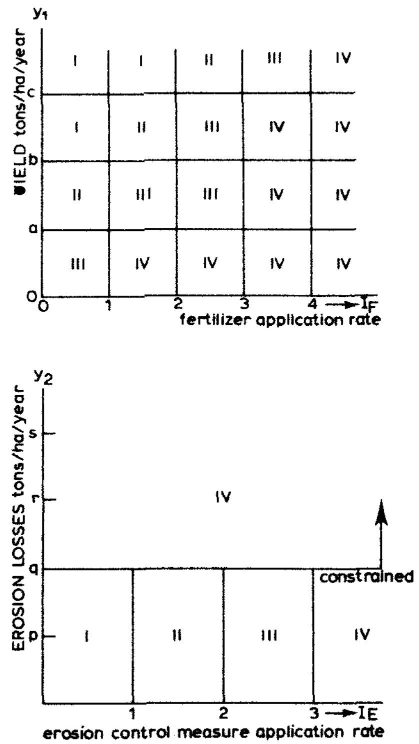


Table 5.9: Diagrammetric presentation of land suitability classes I-IV for matching purposes, based on ranges and levels of values of Y_1, Y_2, I_F, I_E criterion variables.

Soil erosion losses (Y_2) are criterion variables that are often specified as constraints (see Section 5.4.1) in the Criterion Function of a physical land suitability classification, e.g. 'the land must not lose more soil per hectare per year than an amount Y_q' (see Table 5.9), which should be roughly the equivalent of the amount that can be replaced by the soil-forming processes. If the Wischmeier equation

$$A = R \times K \times L \times S \times C \times P$$

is used for measuring the land quality 'resistance to erosion', this equation can be quite helpful during the matching (see also Section 3.1.2).

In the Criterion Function a certain value of $A = Y_q$ (soil erosion losses per hectare) is specified: this should not be exceeded.

Hence, all (LUT, LU) combinations that are expected to result in too high A values ($A > Y_q$) should be eliminated, or classified as unsuitable (=IV) during the matching.

Conclusion

Ideally, land evaluation should be carried out on the strength of observations of real data related to specific sites. But the number of observations of natural phenomena and experiments is necessarily limited in space and time. There is an obvious need for additional techniques to generate information about the expected effect of physical inputs on outputs and land qualities. Making analogies with other areas has been the most common technique for obtaining such additional data. The construction of conversion tables that relate inputs, land qualities and outputs with land suitability classes often uses this method. The analyses of land quality - output relations and input - land quality relations, identified for analogous areas (as described in previous Sections) are expected to help input-output analysis when there is inadequate site-specific information.

The soil series described in the USA using the Soil Taxonomy (USDA, 1976) are expected to be sufficiently homogeneous to permit transfer of experimental results from so-called 'Benchmark' (representative) sites to other sites with soils of the same series which have not been studied directly. Such Benchmark soils are analogue models serving the purpose of extrapolation of experimental results (Dijkerman, 1973).

But one cannot always rely on the correlation with analogous areas, since many development situations are characterized by a unique combination of socio-economic and physical constraints and very specific development objectives.

Other difficulties with the generation of real data to support input-output analysis are the relative slowness of real time experimentation and the fact that some inputs may have an irreversible effect on the land qualities, which interferes with the possibility for repeating and modifying experiments when the observed effects of input application are not needed, e.g. the formation of impermeable layers in the soil or the accumulation of toxic elements.

As the analyses of input-output relations tend to become more and more complex, systems analysis and simulation is now being relied on increasingly. This approach is further stimulated by the introduction of computer-based natural resources information systems (Decker *et al.*, *1975*; Tomlinson *et al.*, 1976; McDougall, 1976).

Systems can be transformed into models to simulate the effects of variable inputs on the land qualities and on the outputs. These models can either be mathematical computer models, or analogue simulation models of the type described by Wind (1976), who uses models in which the flow of water in soils is simulated by flows of water and electricity.

The use of systems analysis and simulation models may modify the data collecting stage in land evaluation, the methods and density of sampling (Stroosnijder, 1976; Bouma, 1977) the techniques of making land resources maps and the classification of land attributes, e.g. the application of a numerical soil classification (de Gruyter, 1977).

An important advantage of using mathematical simulation models, when comparing them with the real systems, is that they can be operated in two directions: the role of the dependent variables (the outputs and the land qualities that need to be improved with inputs) and the independent variables (the inputs) can be interchanged.

The use of simulation models holds much promise and is therefore likely to increase, particularly in view of the temporal and spatial problems of collecting real data.

This becomes even more important because land evaluation is increasingly involved in analysing the possibilities of land use changes in situations where the physical and/or socio-economic conditions are seriously limiting a satisfactory matching between land qualities and land requirements of relevant land utilization types. Therefore the distinction between suitable and unsuitable land becomes more difficult to make in these marginal areas, requiring a very careful analysis of the present status of the land qualities and the effects of physical inputs.

Such a task is likely to be beyond the scope of routine land evaluation. Specialized institutions will be asked more and more to carry out such detailed problem analyses. The capacity for modelling and simulating fundamental land use processes and activities and the willingness of these institutions (which are often located in developed countries and at international research centres) to cooperate with the land evaluators, auger well for more sophisticated analysis (e.g. sensitivity analysis) of complex problems in practical land evaluation, in developing countries too.

Such models will probably relate foremost to specific partial land evaluation problems, e.g. of water management in the soil, drainage, soil tillage, the behaviour of plant nutrients and chemical fertilizers and of potential yield. The use of mathematical models solely for simulating all input-output relations influencing the performance of a land use system will probably remain too complex to satisfy practical land evaluation entirely in the immediate future.

Thus, land evaluation must compromise between scientific ideals and limitations posed by data availability, data reliability, and the possibilities for data handling. Furthermore, land evaluation is concerned with prediction, which signifies that its results cannot pass certain limits of probability because of the variation in weather conditions and in human behaviour. Therefore, data analysis in land evaluation will need to be based on a realistic breakdown of the land use process into well understood sub-processes occurring during finite time periods when the process-conditioning variables and parameters can be identified with a reasonable degree of reliability, e.g. the requirements for water and plant nutrients and their availability during the period $t_n \rightarrow t_{n+m}$. This period may be either a day, a week, or a month depending on the objectives of land evaluation and the available data base.

The ELCROS model (de Wit *et al.*, 1978) and related investigations in the field of ecosystem research and theoretical plant production are increasing our understanding of fundamental biological processes. The authors of ELCROS state that their efforts must be regarded more as a guide to research than a final solution. Their contribution is of great conceptual significance for land evaluation: it heralds the possibility that in the future simulations of agricultural production processes will be based on a much better understanding of the underlying physiological mechanisms. We will have a better insight into the land requirements of specific land utilization types.

In addition, soil scientists and agricultural engineers are increasing our understanding of mechanisms underlying the various soil and water management and engineering practices. Agricultural equipment is being adapted for use in adverse physical environments and for a wider range of socio-economic conditions. The land conditions required for the necessary field operations are becoming better understood.

This means that land resources inventories will need to collect data that explicitly characterize the fundamental environmental regimes (i.e. land qualities) influencing these physiological and agricultural mechanisms and processes to improve the possibilities for land use simulation and the prediction of land use performance.

Meanwhile land evaluation is likely to continue to study input-output relations primarily by observing site-specific data and by transfer of knowledge from analogous areas. Conversion tables will be remain useful for input-output analysis and for translating the values of criterion variables of different dimensions into land suitability classes for specific types of land utilization.

Appendix 3: Definitions of important concepts in systems theory

(Adapted from Toebes in Civil Engineering Analysis, Part II, spring 1975 II-12 (GHT). B: 'Further Definitions and Simple Concepts', II Systems: Perspective Concepts and Procedures)

Black Box - A black box is a system for which the internal structure is unspecified, either by choice or of necessity. Evidently a system element as defined above, is a black box. The function, purpose or nature of a black box is specified by or is to be identified from a comparison of input and output as defined below.

At the initial stage of a system synthesis or a systems identification analysis the system itself is considered as a black box. At the next level of analysis, the system is considered as being composed of a set of black boxes. At a yet further level of detail, several of these black boxes may be promoted to sub-systems which, in turn, contain black boxes, and so on. Black box analysis thus may be a tactic of descriptive systems analysis.

Inputs and Outputs - The systems approach begins by selecting from the Universe a collection of elements that are considered most important and which are related to each other in terms of the questions asked. This process of synthesis is a very difficult creative activity for which no formal rules exist. Subsequently, the questions asked or the point of view taken are made more precise and, on the basis of this, some elements are placed within a systems boundary, SB, and the others are placed in the environment outside SB. A relation between an element inside and one outside of SB is called either input or output.

Inputs and outputs may be material or conceptual. They may be vectors having quantity, quality, time, space, or informational characteristics. For dynamic systems these characteristics may resemble flows.

An 'input-output relation' may be a relabelling for cause-and-effect or stimulus response phenomena.

Decision Variables - In terms of the systems goal, the outputs Y_j may be desirable, undesirable or neutral. The inputs I_i may be controllable, partially controllable or uncontrollable. The controllable and partially controllable inputs are called decision variables.

State Variables and Systems Parameters - Systems elements often have quantifiable attributes that vary with the (history of the) input and output levels. The internal variables, called 'state variables', may or may not be present in the systems equation of the element. State variables may constitute important information of the total system. They may be constrained and thereby constrain the inputs or outputs of systems elements and hence of the entire system.

Systems equations also contain constants. These are called 'systems parameters', if they are subject to changes imposed by systems external to the one under consideration. Varying systems parameters is like an outsider occasionally turning knobs on a black box to alter the way it transforms input into output.

The 'state' of a system is the collection of state variable values, indicating its condition in terms of some question that is being asked.

Discipline Systems - For complex systems there exists the practice to look at the technological, economic, political, ecological and other aspects. Thereby the real system is divided into overlapping sub-systems which could be called discipline systems. Breaking a system into discipline systems is useful because it minimizes the number of systems inputs, outputs, and (hence) decision variables. However, an elimination of too many or all interactions leaves sub-systems that may usefully contribute to discipline systems, but often will no longer involve key features of the original system.

Commensuration - If there are several effectiveness parameters it is usually necessary to make them comparable in order to measure, at least in a mathematical sense, the degree of attainment of 'best'. This may be done by translating or converting the effectiveness parameters into a single commensurate effectiveness parameter. The conversion procedure is called commensuration.

Comment - The above definitions should be taken primarily as representing a convenient jargon in systems analysis. Only for relatively simple and special types of systems could they be found to have any axiomatic power.

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Glossary [1]

AGRICULTURE: Used in this report in a broad sense including all aspects of plant and animal husbandry for production, conservation or recreational purposes and thus including also forestry, nomadic herding, food collecting systems, horticulture, sport fields, etc.

COMPOUND LAND UTILIZATION TYPE: More than one single LUT operating on the same parcel of land but in different sites of the parcel. For the purpose or within the possibilities of land evaluation they constitute one use with one set of land requirements, e.g. strip cropping, mixed cropping.

GENERAL PURPOSE LAND EVALUATION: A standardized procedure for all lands to evaluate their capability to support a generally defined land use.

IMPROVEMENT QUALITY DETERMINANTS (IQD): Measurable characteristics of the land mapping unit that determine its improvement quality (IQ) for specific inputs applied with specified application methods.

INTERNAL LAND REQUIREMENT (LR_i): The land requirement of an individual land utilization type LUT.

INPUTS (I): Selected materials that enter the Land Use System (LUS) for purposes of production, management, conservation and improvement e.g. fertilizers, irrigation water.

INTEGRAL LAND EVALUATION: A land evaluation procedure which is a combination of physical land evaluation and socio-economic analysis.

[1] *Several definitions in this glossary have also been presented in the FAO Framework for Land Evaluation or in the ILRI Publication No.16: Land Evaluation for Rural Purposes.*

INTERNAL LAND SUITABILITY CLASSIFICATION: A classification of land (mapping) units according to the degree in which their internal land qualities meet the internal land requirements of defined land utilization types.

LAND: An area of the earth's surface,the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man.

LAND EVALUATION: The process of assessment of land use performance, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising land uses in connection with specific land units in terms applicable to the objectives of the land evaluation.

LAND IMPROVEMENT: An alteration in the properties and qualities of land which improves its suitability for combination with a particular land utilization type.

LAND MAPPING UNIT (LU): An area of land demarcated on a map and described in terms of land properties and/or qualities.

LAND QUALITY: A (complex) attribute of the land which acts largely as a separate factor on the performance of a certain use, e.g. available water, available nutrients, resistance to erosion. The expression of each land quality is determined by a set of interacting single or compound land characteristics with different weights in different environments depending on the values of all characteristics in the set. A distinction is made in ecological qualities (LQ_s), management qualities (LQ_m), conservation qualities (LQ_c) and improvement qualities (IQ).

LAND REQUIREMENTS (LR): The specific land conditions required for the proper functioning of a certain crop or agricultural implement, e.g. water requirements, workability requirements.

LAND REQUIREMENT DETERMINANTS (LRD): Measurable characteristics of the land utilization type that determine its requirements for specific land qualities, e.g. the rooting habits of a plant or its stomatal characteristics.

LAND SUITABILITY: The fitness of a given type of land for combination with a specified type of land utilization.

LAND SUITABILITY CLASSIFICATION: An appraisal and grouping, or the process of appraisal and grouping, of specific land mapping units in terms of their absolute or relative suitability for combination with specified land utilization types.

LAND USE SYSTEM (LUS): By combining a land mapping unit LU with a pertinent land utilization type LUT a land use system LUS is constructed consisting of a collection of elements and their relationships, selected for their bearing on the questions being asked or the goals pursued, and related to similarly selected land use systems in its environment. LUS is a model of the real land use system.

LAND UTILIZATION TYPE (LUT): A specific way of using the land, actual or alternative, described for the purpose of land evaluation in the following terms of key attributes: (1) produce (e.g. kind of crop), (2) labour, (3) capital, (4) management, (5) technology, (6) scale of operations. It is a technical organizational unit in a specific socio-economic and institutional setting.

MAJOR LANDSCAPE ELEMENT (LE): An area of land demarcated on a map described in terms of properties and/or qualities, and composed of several land mapping units which are functionally related by some common process of movement of mass and/or energy, e.g. a major or minor catchment.

MULTIPLE LAND UTILIZATION TYPE: More than one single LUT operating simultaneously on the same parcel of land each with its own land requirements, inputs and outputs: e.g. recreation and timber production in the same forest area.

OUTPUTS (Y): Materials leaving the Land Use System (LUS), e.g. yield, sediments, drainage water.

OVERALL LAND QUALITY (LQ_o): A land quality of a major landscape element, e.g. the precipitation, interception and water storage capacity of catchment LE.

OVERALL LAND REQUIREMENT (LR_o): The total of individual requirements made by the different land utilization types that operate simultaneously on different land (mapping) units belonging to the same major landscape element LE.

OVERALL LAND SUITABILITY CLASSIFICATION: A classification of land (mapping) units and major landscape elements according to the degree in which their internal and overall land qualities meet the internal and overall land requirements. It takes into consideration the interactions between the envisaged land uses and an assessment of the environmental impact from full-scale implementation of the land use proposals.

PARALLEL LAND EVALUATION PROCEDURE: An integral land evaluation procedure in which socio-economic analysis proceeds concurrently with the physical land evaluation at a comparable level of detail.

PHYSICAL LAND EVALUATION: A land evaluation procedure that is concerned with predicting the performance of specific land use systems, as conditioned by the constraining influence of physical land conditions. Performance is expressed in physical terms, in this report set against 'socio-economic'. The physical land conditions are the only variables that affect the rating of the performance of a land use system, i.e. the physical land suitability classification.

SIMULATION: The building of a dynamic model and the study of its behaviour.

SINGLE LAND UTILIZATION TYPE: A LUT that has land requirements that exclude other simultaneous uses of the land, e.g. large-scale sugar cane production.

SOIL: A three-dimensional body occupying the uppermost part of the earth's crust and having properties differing from the underlying rock material as a result of interactions between climate, living organisms (including human activity),parent material and relief over periods of time and which is distinguished from other 'soils' in terms of difference in internal characteristics and/or in terms of the gradient,slope-complexity, micro-topography, stoniness and rockiness of its surface.

SPECIFIC PURPOSE LAND EVALUATION: A standardized procedure which uses all relevant physical, technological, social and economic data to evaluate land areas on their fitness to support the most pertinent land utilization types. This fitness, or land suitability, is expressed in terms of the effects to be expected and the inputs required.

STAGED LAND EVALUATION PROCEDURE: An integral land evaluation procedure in which the stage concerned with physical land evaluation is followed by a stage concerned with socio-economic analysis.

SYSTEM: A limited part of reality with related elements.

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