Lecture Notes: “Land Evaluation”

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Part 7 : Non-FAO Land Classification Methods

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Contents for Part 7 : "Non-FAO Land Classification Methods"

Many systems have been devised to classify land for specific purposes, and many studies have been completed using them. There is a high probability that the practicing land evaluator will encounter them. Most of these are useful when used for their intended purpose. For each of these systems we will study: (1) objectives, (2) suppositions; (3) the method of classification itself; (4) limitations; and (5) relation to FAO-style land evaluation.

The methods can be divided into (1) land classification methods that were developed before the FAO 'Framework for Land Evaluation', most of which are still very influential; (2) Agroecological Zones, and (3) land classification methods developed since the FAO Framework, but which are outside the Framework.

1. Pre-FAO land classification methods: USA and international adaptations

1.1 USDA Land Capability Classification & international variants

This is undoubtedly the most used land classification system in the world, and the land evaluator will very often encounter it. Original reference: (Klingebiel & Montgomery, 1961). Summary in (McRae & Burnham, 1981) Chapter 5.

1.1.1 Objective

Classify *soil mapping units* (at the phase of soil series level of detail) according to their ability to support general kinds of land use without degradation or significant off-site effects, for farm planning. The original users were District Conservationists of the USDA Soil Conservation Service, who advised farmers on the most appropriate use of their fields. It was not intended to create detailed management plans, only the conservation part of these plans.

1.1.2 Definitions

Capability vs. suitability

Capability refers to general kinds of land use (similar to FAO Framework ‘major kinds of land use’) rather than specific land use systems (FAO Land Utilization Types), for which we talk about *suitability* of land areas. Thus we can not expect to make detailed statements about land use and management in a capability classification.

Class, subclass and unit

Very similar in concept to FAO suitability class, subclass and management unit.

Capability *class*: general degree of ‘goodness’ in the sense of ‘possible intensity of use’: 1 = best, 8 = worst. For some reason the original system used roman numerals I, II, …VIII. We will use Arabic numerals for the same reason we use the SI system of measurement.

Capability *subclass*: indicates the major limitations, by the use of one or more letters. USDA subclasses: ‘e’ = erosion hazard, ‘w’ = excess water, ‘s’ = soil limitations within the rooting zone (includes shallowness, stones, low native fertility difficult to correct, salinity), ‘c’ = climatic limitations (temperature or rainfall). Class 1 has no subclasses.

Capability *unit*: a division of the subclass nearly identical in its management requirements. The degree and general type of limitations are the same in a subclass, but there may be important management differences, for this reason, we want to separate them on the capability map and in the recommendations table. For example, class 3s could be due to excess gravel in the root zone or excess salts; we could assign these unit codes '3s1' and '3s2'. Units are defined locally for each survey and described in detail. They generally correspond to phases of soil series in the detailed county soil survey.

Evaluation units

These are always map units of soil resource inventories, usually of detailed soil surveys suitable for farm plans.

1.1.3 Definition of capability classes

These are textually from (Klingebiel & Montgomery, 1961)

1. Soils in class 1 have few limitations that restrict their use

2. Soils in class 2 have some limitations that reduce the choice of plants or require moderate conservation practices

3. Soils in class 3 have severe limitations that reduce the choice of plants, require special conservation practices, or both

4. Soils in class 4 have very severe limitations that reduce the choice of plants, require very careful management, or both

5. Soils in class 5 have little or no erosion hazards but have other limitations, impractical to remove, that limit their use largely to intensive pasture or range, woodland, or wildlife food or cover. (Note: usually wet soils).

6. Soils in class 6 have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food or cover.

7. Soils in class 7 have very severe limitations that make them unsuited to cultivation and limit their use largely to extensive grazing, woodland, or wildlife.

8. Soils and landforms in class 8 have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, water supply, or to aesthetic purposes.

Note: Increasing class number restricts the intensity of land use. There is thus an implicit ranking of major kinds of land uses: very intense cultivation (1), intense cultivation (1-2), moderately intense cultivation (1-3), limited cultivation (1-4), intense grazing (1-5), moderate grazing (1-6), limited grazing (1-7), forestry (1-7), wildlife (1-8).

Note: all qualifying terms are vague and undefined, e.g. 'severe', 'limit the choice'. It is a written record of the best available judgment, not an objective system of land classification, although in most applications there are tables that give limits of land characteristics that can be accepted in each class, e.g., slope must be <5% to be in class 1 or 2.

1.1.4 Assumptions of the USDA Land Capability Classification

These apply to the original system as developed in the USA.

1. Considers only *relatively-permanent* land characteristics. For this reason, physical LCs such as stoniness are given more weight than chemical LCs such as pH.

2. Within a class there may be very different soils but with the same degree (in a subclass, also kind) of limitations.

3 Not a productivity rating. Class 4 land could be more productive than class 1 but also be more fragile.

4. No attempt to determine profitability.

5. A single, moderately-high level of management is assumed.

6. If major land improvements are made, the land should be reclassified. The cost of the land improvement is not considered.

7. Geographic factors such as distance to market, kinds of roads, size and shape of soil areas, location within a farm or field etc. are not included.

Conclusion: a very narrowly-focused interpretive soil classification.

1.1.5 Classifying evaluation units: (1) direct assignment

The evaluator places the unit in a class according to the class description. For example, if the map unit has some limitations that reduce the choice of plants or require moderate conservation practices, the evaluator places it in class 2. There are no tables or explicit decision procedures, the evaluator chooses the class that best fits the land unit. This is subjective but can be very consistent when used by an experienced surveyor (good example: 7 states of Venezuela classified by Samuel Strebbin). It is also appropriate in settled agricultural areas with a small range of established land uses.

1.1.6 Classifying evaluation units: (2) tables

In an attempt to make the classification more objective (and usable by less experienced surveyors), *interpretive tables* can be constructed, showing the maximum value of land characteristics that can be accepted in each class. For example, class 1 might be defined as requiring slopes <1%, class 2 <3%, class 3 <8%, class 4 <15% etc. These limits are set based on observations of actual land uses. There is no *a priori* reason to pick a particular cutoff, it all depends on the effect on the land use. Limits may vary among regions, e.g. in regions of intense rainfall the slope limits may be lower. Land characteristics can be combined, e.g., slope and topsoil texture. Problem: the tables may misclassify (in the sense of the class definitions) land with unusual combinations of land characteristics.

1.1.7 International adaptations

This system was widely adopted and sometimes adapted to local conditions:

1. Modified number and/or definition of classes.

2. Local rating tables

3. Other subclass letters for locally-important factors

4. Multiple classifications for various management levels (e.g., traditional and 'improved')

5. Class 5 is not a special class, but in the same scale as the others.

Only (4) is really a conceptual advance, anticipating the notion of Land Utilization Type. These sorts of changes led to the development of the FAO Framework.

1.1.8 Conclusion

The LCC obviously influenced the FAO Framework. It is still useful for conservation farm planning and for grouping soil survey map units into general management groups, but for little else. Major problems: (1) completely ignores economic factors, (2) land is not evaluated for specific uses. In the FAO framework, we either evaluate for a LUT or for a specific LQ of interest to conservation, e.g. erosion hazard. Some of the same tables used to evaluate specific limitations can be used as-is to evaluate LQs.

1.2 USBR Land Suitability for Irrigation

Original statement: (U.S. Department of the Interior, 1951). Other explanations: (EUROCONSULT, 1989) p. 146-149, (Food and Agriculture Organization of the United Nations, 1985) p. 103-109, (Landon, 1984) p. 47-52, (McRae & Burnham, 1981) p. 127-133, (Maletic & Hutchings, 1967)

1.2.1 Objective

To select lands for irrigation development, and to characterize their main management factors. The suitability maps are used to plan location of major and minor irrigation and drainage works, and to make project-level decisions on financing etc. The view of land is very much as a resource which can be modified, but whose modification must be sustainable and cost-effective. It is an engineer's mentality ("nature to be commanded").

1.2.2 Principles

1. *Prediction*: The system specifically looks into the future and makes predictions about how the land would appear if irrigated and/or drained, including changes in water table, salinity or sodicity, and land shaping.

2. *Economic correlation*: Physical factors are functionally related to economic value, which is measured by the *repayment capacity*: the residual available to pay for *water* after all other costs have been met. (Another way to express this would be the *return to water* of the land utilization type.) The planner can then set a *repayment threshold* to determine which lands should be included in an irrigation project.

3. *Permanent and changeable factors*: We must identify those factors that *will* change when the project is implemented, and those that will *not*. E.g., soil pH vs. soil texture. One of the aims of the evaluation is to decide which factors can economically be changed; depending on the scope of the project almost anything can be changed. For example, soil material can be transported to change texture.

4. *Arability* and *-irrigability*: The USBR system has two major steps: (1) identify *arable* lands that are suitable for irrigation according to their repayment capacity; (2) within the arable lands, identify the *irrigable* lands that will be actually irrigated. Arable land may not be irrigated because of geographic constraints, such as unfeasible delivery of water, or an isolated or odd-shaped parcel.

1.2.3 Terminology

1. *Arable land*: "Land which, in adequately-sized units and if properly provided with the essential improvements of leveling, drainage, irrigation facilities and the like, would have a productive capacity, under sustained irrigation, sufficient to: meet all production expenses, including irrigation operation and maintenance costs and provide a reasonable return on the farm investment; repay a reasonable amount of the cost of project facilities; and provide a satisfactory standard of living for the farm family." (Note the explicit social and economic context.)

2. *Irrigable land*: "Arable land under a specific plan for which water supply is or can be made available and which is (planned to be) provided with irrigation, drainage, flood protection, and other facilities necessary to sustain irrigation."

3. *Productive land*: Irrigable land, less land area for canals, farm buildings and other land which won't grow crops. Often considered to be 94-97% of the irrigable land.

4. *Land class*: A category of land with similar repayment capacity. Different lands in this class may have quite different physical characteristics.

5. *Land subclass*: A category within the land class with a specific set of physical characteristics that lead to a specific type of limitation.

1.2.4 Farm budgets as economic indicators

The evaluation unit is the ‘typical’ family farm. An economic study is undertaken of the farm budget on a hypothetical ‘typical’ farm on each of the major land classes and subclasses. This requires that the economist establish one or more reference cropping/livestock patterns and quantify the major inputs and outputs to the system, both their amount and timing. The *net farm income* can then be calculated. This can be normalized to a per-hectare basis by dividing by the number of irrigable hectares on the typical farm, thus obtaining a per-hectare repayment capacity.

The per-hectare repayment capacities, summed over the project area, are used to estimate the maximum cost of the irrigation scheme (i.e., overall project feasibility), using current or projected interest rates.

Problem: in countries without experience in irrigation projects, or where farmers do not keep farm budgets (e.g., only partly in the cash economy), the economic evaluation may be tentative.

1.2.5 Definition of land classes

Class 1: “Arable” : high repayment capacity; usually allow a wide range of crops and a high sustained yield; water is usually used efficiently; the least expensive lands to develop

Class 2: “Arable” : intermediate repayment capacity; usually allow a somewhat restricted range of crops and moderate sustained yields; water is usually used moderately efficiently; may be more expensive to develop than class 1.

Class 3: “Arable” : Similar in their repayment capacity and productivity to class 2, but more risky to develop because of serious single deficiency, or a combination of several moderate deficiencies, that must be corrected in order to bring the land into production.

Class 4: “Limited Arable or Special Use” : suitable only to a very limited range of crops (therefore, more risky because only one commodity can be grown). Their repayment capacity may in fact be higher than Classes 2 or 3. Usually, the crop is indicated, e.g. ‘4R’: rice, ‘4P’: pasture, ‘4F’: fruit trees.

Class 5: “Temporarily Non-Arable” : Not arable because of a specific deficiency that could be removed; further studies (engineering, agronomic, or economic) are needed to place it in class 6 or an arable class. This class is used in preliminary maps only.

Class 6: “Non-Arable” : Impossible or unfeasible to develop under existing or projected economic considerations. Includes *prima facie* undevelopable lands such as rough broken land, as well as lands that could be developed but which would not meet repayment criteria.

1.2.6 Modification for SE Asia

In the original system, most rice land goes into class 4, which doesn't look so good on the project plan. So the following modifications have been made:

Class 1: "Arable - diversified crops"

Class 2: "Arable - diversified crops"

Class 1R: "Arable - wetland rice"

Class 2R: "Arable - wetland rice"

Class 6: "Non-arable"

1.2.7 Definition of subclasses and the USBR mapping symbol

On a USBR map, each land area gets an informative symbol, showing the land class, the subclass (due to major deficiencies in 's'oil, 't'opography, and/or 'd'rainage), a land use code, a relative productivity code, a relative development cost code, a farm water requirement code, and a drainability code. Thus land in the same land class (equal repayment capacity) may differ significantly in these factors.

In addition, the *specific deficiencies* that led to a 's', 't', or 'd' subclass designation can be listed, along with their *severity level*. Each deficiency is assigned a letter, e.g., 'z': coarse texture (this would lead to a 's' subclass).

The final map unit symbol is thus a very informative guide to management once the project is implemented.

1.2.8 Classifying evaluation units

Almost always, *matching tables* are developed that relate *diagnostic land characteristics* to specific limitations and subclass letters, as well as to the land class. It would seem that *yield estimates* would be needed for each combination of land characteristics; in practice these are estimated as yield reductions from some reference level.

1.2.9 International adaptations

This system has been widely used outside of the USA for irrigation project planning. The main adaptations have been:

1. Local context for wealth expectations, farm size, and costs (these must be locally estimated, according to the system)

2. Different classes, subclasses and specific limitations.

1.2.10 Relation to FAO Framework

The USBR system heavily influenced the framework, especially the idea that only economic considerations can truly classify land for development projects. The emphasis on specification of the typical farm in its social context is similar to the emphasis on the Land Utilization Type. The subclasses are general Land Use Requirements; the other map unit codes (e.g., land development cost) could be considered as specific Land Use Requirements.

1.3 Soil Survey Interpretations

The basic idea is to take the map units of a detailed soil survey (e.g., US county level, map at 1:20 000, map units are phases of soil series) and *interpret* them directly for anticipated land uses. The result is a *suitability* for the use based on the severity of *relatively-permanent limitations*. It is *not* an economic evaluation, although the relative difficulty of overcoming the limitations is implicitly taken into account. Most often, this approach is taken for *non-agricultural* uses, such as engineering uses, whose limitations and 'productivity' can't easily be quantified in the context of a soil survey.

(Olson, 1981) is a textbook that uses this approach. (Olson, 1973) is an example for engineering applications such as suburban construction. Any post-1970 soil survey from the USA has interpretive tables that follow this approach. The National Soils Handbook (U.S. Department of Agriculture, 1983b) §603.03 explains the approach, and has sample tables.

Example: (from (U.S. Department of Agriculture, 1983b) Table 603-10)

Classification for septic tank absorption fields

Property	Limits: Slight	Limits: Moderate	Limits: Severe	Restrictive Feature
USDA Texture			Ice	*Permafrost*
Total Subsidence (cm)			>60	*Subsides*
Flooding	None	Rare	Common	*Flooding*
Depth to Bedrock (cm)	>180	100-180	<100	*Depth to rock*
Depth to cemented pan (cm)	>180	100-180	<100	*Cemented pan*
Surface ponding			yes	*Ponding*
Depth to high water table (m)	>1.8	1.2-1.8	<1.2	*Wetness*
Permeability of 60-150cm depth (cm/hr)	5-15	1.5-5	<1.5	*Percolates slowly*
Permeability of 60-100cm depth (cm/hr)			>15	*Poor filter*
Slope (%)	<8	8-15	>15	*Slope*
Fraction >7.5cm (weight %)	<25	25-50	>50	*Large stones*
Downslope movement			susceptible when loaded, excavated, or wet	*Slippage*
Formation of pits			susceptible due to melting of ground ice	*Pitting*

The 'properties' (leftmost column) are land characteristics that are known for each soil unit to be rated. The table is a maximum-limitation table: the rightmost column of 'slight', 'moderate' and 'severe' that applies gives the rating. Each map unit gets the rating *and* a list of the restrictive features.

Advantages: directly applicable to planning; if a decision procedure was developed, it provides insight into the land use. The type of limitation is made explicit.

Disadvantages: most reports don't indicate how the map units were rated (i.e., the report itself doesn't include the rating table). ALES decision trees could be created to do the interpretation, but sometimes the criteria are more 'holistic' (may give an good classification, but can't be reproduced). Example of holistic criterion: 'downslope movement' in the above example; this itself is an interpretation.

Remember, it is not an economic interpretation; the cost to overcome a limitation is only implicit. Some limitations may feasibly be removed, others not, within the context of a LUT. In the above example, it is difficult and expensive to blast away bedrock, but the depth to water table may be controlled by drainage in certain sites. Engineering feasibility is not considered in the ratings, this would have to be determined for each site.

Relation to FAO-style land evaluation: the land uses (individual tables) can be considered to be Land Utilization Types. The limitation types can be considered to be Land Use Requirements. The diagnostic soil variables can be considered to be diagnostic Land Characteristics.

1.4 Parametric indices

(van Diepen *et al.*, 1991) p. 182-184, (Sys, 1985) vol. 2. p. 185-196; (Koreleski, 1988, Storie, 1933), (McRae & Burnham, 1981) chapter 6

The name 'parametric' is unfortunate, since it has nothing to do with parameters in any mathematical sense. Better would be 'multi-factor' indices.

1.4.1 Objective of parametric indices

Basic idea: single numeric factors (usually values of land characteristics) are combined to reach a final single numeric rating. Thus all land is rated from excellent (100) to useless (0), and this is assumed to be a ratio scale, i.e., land rated 80 is 'twice as good as' land rated 40. Thus it would be a 'fair' basis for taxation (just like property assessments).

Factors can be combined by *adding* or *multiplying*, and possibly *normalizing*, depending on the system.

1.4.2 A multiplicative index: the 'land index'

The *Land Index* is a multiplicative index, derived from any number of factors which affect the 'value' of the land, usually land characteristics. The purpose is to arrive at a single number representing the 'goodness' of the land area, usually on a scale of 0-100.

Originally derived for land taxation (California 1930's 'Storie Index', since revised several times). The formula is:

$$LI = \frac{\prod_{i=1}^{q} R_i}{100^{q-1}}$$

where the R_i are the individual factor ratings, on a scale of 0-100, and q is the number of factors, so that the denominator normalizes the result to 0-100.

More important factors are rated from 20-100, less important from 80-100 (so they can't have a value less than 80, thus limiting their effect on the LI). This is evidently an *a priori* weighting with no objective basis.

In the original Storie index, there were 3 factors: soil profile, topsoil texture/stoniness, and miscellaneous limitations such as drainage.

Example: soil profile 80/100, topsoil texture 60/100, miscellaneous 90/100. LI = $(80)(60)(90)/(100)^{3-1}$ = 43.2

Problems of a multiplicative index: misleading sense of accuracy, arbitrary choice of factors, factor ratings without validation, assumes synergistic interactions in factors, more factors lead to lower average ratings, severe error propagation, weak concept of LUT (there could be different rating scale for different uses, but this is rare; usually a 'typical' agricultural use is considered).

1.4.3 A multiplicative index: the 'Productivity Index'

This is a multiplicative index that attempts to correlate its factors to yield. An example is the Productivity Index (PI) of (Pierce *et al.*, 1983), which was intended to quantify the contribution of certain factors, which are affected by erosion, to yield. The basic idea is to determine the 'sufficiency' of A = available water capacity, C = bulk density and D = pH for root growth, as weighted by an idealized root distribution WF over the profile, assumed to be n layers down to 1m depth. We arrive at the multiplicative index:

$$PI = \sum_{i=1\ldots n}(A_i \times C_i \times D_i \times WF_i)$$

Each of the variables is standardized to 1.0 for ideal root response, 0.0 for complete crop failure. This index was intended for deep-rooted crops, but could be adapted for others by limiting the soil depth considered.

Problems: calibrating each factor independently, assuming that their interaction is multiplicative!

1.4.4 An additive index

Another method is a simple *point system*, with different factors being allocated a portion of, say, 100 total points.

For example: 40 points for soil physical properties, 30 points for soil chemical properties, 30 points for site characteristics (e.g., topography).

The LESA system (later lecture) is an example.

1.4.5 Use of parametric indices

These have been surprisingly popular, despite their obvious limitations: rigid structure, no economic content, arbitrary weights.

Why? To give one single number for taxation or to rate land from 'good' to 'bad'. We will see that the Soil Potential Rating of the USDA/SCS is an additive index with a modern flavor.

Judgment of (van Diepen *et al.*, 1991): "Despite their apparent quantitative approach, the parametric methods are qualitative assessments"(p. 184). This because the factors and their weights are subjective.

1.5 Yield estimates

(van Diepen *et al.*, 1991) pp. 178 ff. is an introduction to many methods of yield estimation.

A very useful land evaluation, where possible, is a direct *estimate of crop yield* on a land mapping unit. This is only possible where the crop is widely grown and where sufficient yield data has been collected. Yield estimates refer to *long-term averages* and, possibly, *variability* of yields (e.g., (Dumanski & Onofrei, 1989)).

The National Soils Handbook (U.S. Department of Agriculture, 1983b) §603.10-1 explains one approach to direct yield estimation. Here the Land Utilization Type is a combination of the input level, cropping system, and variety. The approach works best where a one or two LUTs represent most of the area dedicated to a crop.

The aim is to establish an *expected yield* and, if possible, a *range* of probable yields, of each adapted crop on each map unit, for a specific LUT. Because yield is so variable, and affected by so many factors, a large amount of art and expert judgment goes into the estimates.

The process is in two steps: (1) a quantified estimate on several *benchmark soils*, i.e., important and extensive soils which between them cover most of the range of soil properties in a region, and then (2) an expert judgment of yields on other soils, with reference to the benchmark soils and the differences between the benchmark soils and other soils with respect to key properties known to affect yield (from step (1)), such as water-holding capacity.

1.5.1 Data collection

We always need some objective measure of yield. Yields can be measured from (1) farmer's fields, (2) field trials for fertilizer, variety, tillage etc., (3) research plots at experiment stations.

For each yield measured, we must quantify the factors that might affect it, including (1) the *soil mapping unit* where the yield was measured, (2) the *management practices* used to produce the yield (cropping history, planting and harvest management, type and amount of organic and inorganic fertilization, type of insect and disease control), (3) the *weather* during the period when the yield was obtained (especially precipitation and temperature), (4) the *variety*, (5) the *site position* (landscape element, length of slope above the site, slope gradient and aspect).

1.5.2 Data processing

Yields from the three sources can be *standardized* to a common scale (usually the farmer's fields) by multiplying a correction factor which takes into account the more intense management on research plots and, to a lesser extent, on field trials. The corrective factor can be estimated from the ratio of the overall average of yields from each source.

The effect of the yield-producing factors would best be quantified by an *analysis of variance*, which would reveal the importance of each factor individually as well as interactions. Often there is not enough systematic data to do this (plant breeding plots are an exception). Another approach is *regression analysis* on a range of predictor variables, as we studied earlier in the course. Again, the results can be inconclusive.

If the trials can be grouped by management practice (e.g., if most farmers in the area use similar tillage and fertilization practices), then the yields in the group can be *ranked* to give a *proportional yield* on each soil. The proportion can then be multiplied by a *reference yield* to give the expected yield for each soil unit.

1.5.3 The expert committee

Once the yield relations for benchmark soils has been established, an *expert committee* of soil scientists, agronomists, and conservationists estimates the relative yields on all non-benchmark soils, taking into account key differences. For example, if a map unit differs from a benchmark soil only in being shallower, the difference in rooting volume and available water capacity can be estimated, and then the effect on yield due to this single factor.

In practice, very good results can be obtained for *all* soils, from a local committee of soil scientists, agronomists, and farmers (if they are willing to reveal yield information). It turns out to be fairly easy to *rank* the soils in a survey area and assign to each group a *proportional yield* referring to a local optimum or reference level. This works because humans are good at comparisons, not so good at absolute estimates.

2. Agro-ecological Zones (AEZ)

The term 'Agro-ecological zones', abbreviation AEZ, refers to any method for dividing the earth's surface into more-or-less homogeneous areas with respect to the physical factors that are most important to crop (or other plant) production. The term first came into prominence with the FAO's effort of the mid 1970s to determine potential human carrying capacity, and it is this original system which we will study. Be aware that a similar product can be produced by other methods; however, the basic idea of producing maps of quantitative assessment of crop adaptability is common to all AEZ studied.

Original reference: (Food and Agriculture Organization of the United Nations, 1978) for Africa, and subsequent volumes for Southeast Asia, Southwest Asia, and Central & South America. The land evaluator can use the 1:20'000.000 (OLD = 160,000 km^2) result maps for general ideas of crop suitability, or can use the methodology itself to produce larger-scale maps. An example of larger-scale AEZ is (Kassam *et al.*, 1991), which is the first country-level study (Kenya, at 1:1'000.000) following the continental studies.

2.1 Objective

Continental studies: "To obtain a first approximation of the production potential of the world's land resources, and so provide the physical data base necessary for planning future agricultural development.". It is explicitly aimed at potential production of human energy crops (rice, maize, sorghum, pearl millet, wheat, soybean, phaseolus bean, cassava, white potato, sweet potato) as well as cotton, given the physical resource base, especially climate and to a lesser extent soils, not taking into account social and economic factors. The geopolitical questions are: what is the human carrying capacity in each political division? and what are the implications for migration pressure?

Country-scale studies are intended to zone rural development policies (credit, infrastructure, research). These try to answer more specific questions, e.g. "Where can maximum returns from increased inputs be obtained and on what land uses?", "What levels of investment are needed to obtain these returns?", "Where should research, extension, and education efforts be concentrated?" Already we see that AEZ grades into economic land evaluation when it is applied at a larger scale.

2.2 Outputs of the continent-scale studies

1. A global, quantitative *climatic classification* for rainfed agriculture, for each of the chosen crops.

2 An agro-climatic *adaptability* classification (for each crop), in a form suitable for matching crops with climate and soil resources

3. Crop production cost data by soil and climatic zone, sufficient to judge whether yields exceed costs.

4. For each crop, a map of *suitability classes* S1, S2, S3/N1 and N2, based on predicted relative biomass production (>80%, 40-80%, 20-40%, <20% of the constraint-free yield), for *two* technology levels (high and low inputs) which define a general Land Utilization Type.

2.3 Climatic requirements of crops

These include *moisture* (from rainfall and soil storage), *temperature*, *radiation*, and *photoperiod*, as they affect *growth* and *phenology*. This data is synthesized into interpretive climatic maps: (1) *length of growing period*; (2) *pattern of growing period*; (3) *thermal zone*.

The crops are grouped according to their *photosynthetic pathway* (C3, C4, C4 adapted for highlands) as this greatly affects how the plant responds to moisture and temperature.

The key innovation is the *length of growing period*, which in the tropics is based on rainfall patterns and in the subtropics also on temperature. This is used to quantify yield reductions.

2.4 Soil requirements of crops

These include *internal* requirements (e.g., soil temperature, moisture, aeration, fertility, depth, stoniness, salinity and other toxicities) and *external* or *site* requirements (e.g., slope, micro- and macro-relief, occurrence of flooding during the growing period, accessibility and trafficability). In these studies, major land improvements (irrigation, drainage, leaching, land shaping etc.) are *not* contemplated.

So these are really soil and landscape requirements. For each of these, a table is established with *optimum* and *extreme* values. For example, salinity for soybean: optimum is 0 to 4 dS m^{-1}, extreme values are 0 to 6. The optimum level is associated with yields from 80-100% yield.

2.5 Soil resource inventory

The FAO Soil Map of the World at 1:5'000,000 was used as the soils map. It is recognized that this document is of very uneven quality; the map itself shows three degrees of reliability. The soil properties necessary for the evaluation are inferred from the map unit name, which in turn implies certain diagnostic horizons, and the map unit phase, for slope and texture. The scale and level of detail of this map is well-matched with the objectives of the study.

In a country study, a more detailed soil map (e.g. 1:1'000.000 or 1:500.000) is needed.

Note that a general soil map can list several *components* for each map unit; although these can not be shown on the map due to scale constraints, each can be described and interpreted separately, and the proportion of the map unit covered by the component can be listed. Thus accurate computations of suitable areas are possible even with small-scale maps.

2.6 Relation to FAO-style land evaluation

The original study is not a detailed land evaluation because the LUTs are crudely defined; the country studies have more detail. The AEZ can be interpreted for many of the 'agro-ecological' LURs in a land evaluation, e.g. growing period, radiation regime, harvest conditions. The FAO's AEZ uses the Framework for Land Evaluation definitions of suitability based on relative yield, and also adopts the basic principles of the Framework as a starting point. The country studies explicitly follow the Framework.

In a sense, any land evaluation for agricultural crops must include an AEZ, even if this is not explicitly stated.

3. Modern non-FAO land classification methods

For well-defined planning objectives, special-purpose systems can give rapid, reproducible results at acceptable precision.

3.1 The Fertility Capability Soil Classification System (FCC)

This system is explained in (Sánchez, Couto & Buol, 1982). Christopher Smith of the USDA/SCS, a student of Stan Buol's, expanded and updated the system in a recent PhD thesis (Smith, 1989), which has not been published in a journal.

This is a good example of a soil classification (*not* a ranking of soils!) that serves a specific purpose without pretending to be a land evaluation. It is interesting in itself and can serve as an important input to land evaluation.

3.1.1 Objective of the FCC

"The Fertility Capability Soil Classification System (FCC) was developed as an attempt to bridge the gap between the sub-disciplines of soil *classification* and soil *fertility*." (Sánchez, Couto & Buol, 1982, p. 283). FCC is an example of a *technical* soil classification system, i.e., soils are classified for a particular purpose, not according to supposed natural relationships, as in a *natural* soil classification system.

3.1.2 Structure of the FCC

"FCC is a technical system for grouping soils according to the *kinds of problems* they present for agronomic management of their *chemical* and *physical* properties. It emphasizes *quantifiable* topsoil parameters as well as subsoil parameters directly *relevant to plant growth*. FCC-classes indicate the main fertility-related soil constraints, which can be interpreted in relation to specific farming systems or land utilization types." (Sánchez, Couto & Buol, 1982, Abstract)

An FCC code consists of three components: (1) Type, (2) Substrata type (optional), (3) Modifiers (optional).

Type: the general field texture of the plow-layer or surface 20cm, whichever is shallower: S = sandy (USDA sand and loamy sand), L = loamy, C = clayey (>35% clay), O = organic (>30% O.M. to at least 50cm).

Subtype: used only if there is a *marked textural change* from the surface: S, L, C as for Type, R = rock or other hard root-restricting layer within 50cm.

Either or both the type and subtype can also include a prime (') symbol to denote 15-35% gravel or coarser, or a double prime (") to denote >35% gravel or coarser.

So, these two give a *general* idea of the water-holding capacity and exchange surface within the rooting zone.

Modifiers: 13 lower-case letters, which can be used alone or in combination, to indicate important facts about the chemical or physical properties of the soil that have a direct effect on soil fertility management. Each is determine from one or more *diagnostic land characteristics*.

Examples of modifiers

e low cation exchange capacity in the surface soil. Must have one of the following diagnostic LCs: (1) CEC <4 meq/100g soil by sum of bases+KCl-extractable Al ('effective CEC'), or (2) CEC < 7 meq/100g soil by sum of cations at pH7, or (3) CEC < 10 meq/100g soil by sum of cations + Al + H at pH8.2.

v vertisol (very sticky plastic clay). Must have one of the following diagnostic LCs: (1) >35% clay and >50% of clay fraction is 2:1 expanding clay

d dry: ustic, aridic or xeric moisture regimes (Soil Taxonomy), i.e., subsoil is dry > 90 cumulative days per year within 20-60 cm depth.

Others are g (gley), a (Al toxicity), h (acid but not Al-toxic), i (high P-fixation by iron), x (amorphous minerals), k (low K reserves), b (basic reaction), s (salinity), n (natric), and c (cat clay).

3.1.3 Interpretation of FCC nomenclature

The whole idea of FCC is that the soil 'name' as given by its FCC is meaningful for soil fertility management. Examples:

'Lehk' : good water-holding capacity (L throughout, no primes), medium infiltration capacity (L), low ability to retain nutrients, for plants (Le), deficient in bases (hk); heavy applications of bases and N should be split to avoid leaching (Le), requires liming for Al-sensitive crops (h), potential danger of over-liming leading to unavailability of micronutrients (e), low ability to supply K (k) so that K-fertilizers will be required for plants needing high levels of K.

'LCg' : erosion will expose undesirable clay-textured subsoil (C), drainage limited so that tillage operations may be restricted (g) and some crops may be adversely affected by water in the lower root zone (g). In low-lying positions that can be flooding, an ideal paddy-rice soil.

3.1.4 Interpretation of soil maps with FCC

Provided sufficient information is available in the descriptive legend, or implied by the classification system, existing soil maps can be reclassified into FCC maps. (Sánchez, Couto & Buol, 1982) were able to interpret the FAO Soil Map of the World, using the legend description, phase information for each map unit, a general map of soil moisture regimes, and papers on plant nutrient relationships of soils as classified in the FAO legend. Example: FAO map unit Af18-1a (a Ferric Acrisol, coarse-textures) = FCC class Scdaek.

Then the FCC class map can be reclassified for any specific modifier or combination of these. For example, a map can be produced of all the soils where Al-toxicity is likely, or where split applications of N fertilizer would be recommended.

3.1.5 Problems with FCC

The system has been criticized for some of its specific class limits (e.g., why 15-35% coarse fragments for the 'prime' modifier, why not 10-20% etc.). Many of these correspond to the limits in Soil Taxonomy. They could be modified locally, and in fact Smith changed some of these in his revision.

Another criticism is that the classes are not precise enough to make specific fertility management recommendations. This seems unfair given the purpose of the system, which is to indicate the general kind of limitations. FCC units can always be divided into sub-units according to local criteria. Again, Smith divided some classes into two.

My criticism is that the structure of the code is inconsistent, especially the revision by Smith. Example: modifiers h and a are really two intensities of the same phenomenon (soil acidity) and would more logically have been expressed as one modifier plus the intensifier ' (e.g., h and h'). In the revision, the prime is used inconsistently.

3.1.6 Use of FCC in FAO-style land evaluation

The FCC modifiers (letters) can be directly related to individual *land qualities*. For example, the g modifier is directly related to the LQ 'Oxygen availability to roots'.

A group of FCC modifiers together could define a LQ. For example: for the LQ 'susceptibility to erosion', FCC classes Ci, Cx and Lx would be little susceptible (within a given slope class) because of their very high permeability; modifiers v and bv would indicate highly-erosive soil materials; soils with a textural change to clayey subsoils (e.g., SC, LC) or to rock (e.g., SR or LR) would be highly degraded in the case of erosion, also are susceptible to mass erosion if the finer-textured surface layer saturates.

So, if a FCC map is available, it can be very valuable for defining fertility-management related Land Qualities. A problem is the general nature of the FCC classes (unless there are local modifications); usually only two or three severity levels can be separated by the FCC code.

3.2 LESA: A successful land classification for farmland protection

A general introduction is in (van Diepen *et al.*, 1991) pp. 191-2. The original system is presented in (U.S. Department of Agriculture, 1983a). Example applications are given by (Dunford *et al.*, 1983, Van Horn, Steinhardt & Yahner, 1989, Wright *et al.*, 1983). A critical examination of the first decade of LESA implementation is (Steiner, Pease & Coughlin, 1994) with a brief overview by (Coughlin *et al.*, 1994)

3.2.1 Objective of LESA

"LESA was developed by the [US] Soil Conservation Service (SCS) to help implement the 1981 Farmland Protection Policy Act. The system's primary purpose was to provide local decision makers with *objective* and *consistent numerically-based* system of determining which farmland should be available for development and what should be protected for farming." (Daniels, 1990) p. 617. The basic idea is to identify the land that is 'the best farmland' in two senses: its inherent productive capacity and the possibility that a farm on the site can be economically and politically viable.

LESA been applied to the purchase of development rights in critical farmland areas: limited money to be spent for maximum public benefit. Other important applications are in zoning permissions for non-farm and farm-related uses, the designation of agricultural districts, transfer of development rights, and property tax assessment.

LESA is a procedure and framework, intended to be refined and calibrated locally. The original statement (U.S. Department of Agriculture, 1983a) is used by the Soil Conservation Service, unless superseded by locally-developed LESA systems.

3.2.2 Implementation of LESA

Two steps: (1) *design* of the local system: decide on factors to be used and assign weights; (2) *application* of the local system to individual parcels in response to specific questions, e.g., which development rights to purchase. In the first step, all the interest groups and technical experts are involved: SCS, town and country planners, farmers, developers, agribusiness, politicians. In the second step, a smaller group representing the same interests actually makes the ratings. The first step is critical for an objective application of the system, because this is when the factors are weighted without regard to their effect on *specific* properties.

3.2.3 Structure of LESA

Although LESA pretends to be objective and numeric, in fact it is highly subjective. However, the subjectivity is not hidden but explicit in the formulation and application of the system.

Two major criteria: (1) inherent *productive quality* of the land, (2) local development pressure vs. existing agricultural economy, the first usually contributing 100 points and the second 200-points to a maximum score of 300 points (the mix can be adjusted for a local LESA system). Note that the geographic and geo-economic factors (the site) are twice as important as the inherent productivity of the land.

The evaluation unit is usually the *farm* but could be individual fields. The planners either set hectarage targets and include the best lands up to that target, or set a minimum score that must be achieved by a farm to be considered for preservation. Although the *absolute* scores are without real meaning, the *ranks* should be consistent, and this is all that is usually needed.

3.2.4 'Land evaluation' (LE)

Criterion (1) or *land evaluation* (LE) (note this is a very restricted use of the title of this course!) is basically implemented as yield estimates for a *reference crop* using standard technology of the area. There is not too much controversy here, and standard SCS rating tables are almost always used as-is. Local calibration: which reference crop, which technology? Yield estimates are from historical data or soil survey interpretations (note: in the US, all county-level soil surveys include yield estimates for the major field crops). Problem: what about non-reference crops that may be high-value and hard to replace, e.g. orchards? The system works well in areas where cash grains are predominant.

(These reference yields are often expressed by the *soils potential rating*, see other lecture.)

3.2.5 'Site assessment' (SA)

Criterion (2) or *site assessment* (SA) is much more complicated and controversial. A local committee considers and weights factors that favor *agriculture* such as 'size of farm', 'proportion of class 1 and 2 farmland on farm', 'proximity to support services (such as feed and fertilizer dealers)', and those that favor *development*, such as 'extent of non-agricultural development within ... km', 'current zoning', 'proximity to municipal services'.

The SA factors are grouped into categories such as (1) economic viability of farming, (2) existence of policies supporting agricultural use, (3) lack of development pressure. Under category (1) are included the existence of infrastructure (e.g., machinery repair) and markets (e.g., a grain elevator).

In a study of LESA implementations, (Coughlin *et al.*, 1994) report that a typical SA uses 10 to 20 factors, many of which are fairly subjective. Some of the factors are correlated, so there may be bias in the final SA rating.

Conclusion: a very *subjective* system with respect to the site assessment, yet *transparent* (all the assumptions and weightings are mad explicit).

3.2.6 LESA and GIS

LESA is a natural for a GIS implementation (Williams, 1985) since so many of the factors are geographic: e.g. adjacency to farm or non-farm properties, fragmentation of the landscape, distance to agricultural or urban infrastructure. Some of these are too difficult for routine determination without a GIS.

Also, as the weights are changed, the local committee can see interactively the changes in the areas to be preserved or abandoned to development. The LESA scores of an entire area can be summed to give an index of 'farm friendliness', and this score can be evaluated for different development scenarios.

3.2.7 Relation to FAO-style land evaluation

A specific question to be asked of LESA could be considered a *Land Utilization Type*, e.g., land to be included in an agricultural district.

The LE and SA could be considered to be two *land qualities*, the first including all in-*situ*, and the second all *geographic,* factors. However, the factor groups of SA could also be considered individual LQs.

The diagnostic factors (e.g., productivity index, distance to agricultural support services, adjacency to existing development) could be considered as *diagnostic land characteristics.*

3.3 Soil Potential Ratings

The concept of SPR is introduced in (Beatty, Petersen & Swindale, 1979) p. 108-110. The National Soils Handbook §603.09 (U.S. Department of Agriculture, 1983b) explains the system and procedures in detail. The name is misleading and the ratings are of questionable value; however the system is included here because it is intended to replace the simple soil survey interpretations with a more economics-based approach.

3.3.1 Definition

Soil potential ratings are classes that indicate the *relative quality* of a soil for a *particular use* compared with other soils of a *given area*. The following are considered in assigning ratings: (1) yield or performance level, (2) the relative cost of applying modern technology to minimize the effects of any soil limitations, and (3) the adverse affects of any continuing limitations on social, economic, or environmental values.

3.3.2 Objective

A more modern approach than the Storie-index to quantifying the relative goodness of land using a parametric index. These ratings are used for planning purposes, not for recommendations for land use. They measure the relative suitability for a land use. In this sense, they can help planners prioritize lands to be maintained in agriculture. They also identify the general source of the problem. They are especially intended to replace limitations tables, which are based on physical factors without explicit economic interpretation.

A major objective of the SPR, as a replacement for limitations tables (e.g., soil survey interpretations as presented in a previous lecture), is to give an approximate *economic value* to limitations.

3.3.3 Classification

Criteria are established *locally* for the area in which the ratings are to be made. The following classes are recognized:

1. Very high potential. Production or performance is at or above local standards because soil conditions are exceptionally favorable, installation or management costs are low, and there are no soil limitations.

2. High potential. Production or performance is at or above local standards; costs of measures for overcoming soil limitations are judged locally to be favorable in relation to the expected performance, and soil limitations continuing after corrective measures are installed do not detract appreciably from environmental quality or economic returns.

3. Medium potential. Production or performance is somewhat below local standards; *or* costs of measures for overcoming soil limitations are high, *or* soil limitations continuing after corrective measures are installed detract somewhat from environmental quality or economic returns.

4. Low potential. Production or performance is significantly below local standards; *or* costs of measures for overcoming soil limitations are very costly, *or* soil limitations continuing after corrective measures are installed detract appreciably from environmental quality or economic returns.

5. Very low potential. Production or performance is much below local standards; *or* there are severe soil limitations for which economically feasible measures are unavailable, *or* soil limitations continuing after corrective measures are installed seriously detract from environmental quality or economic returns.

Notice the use of *or* conditions. The concept of economic feasibility is explicit in this system.

3.3.4 General concept of the Soil Potential Index

The *ratings* are classes based on the *index*, which is a numerical rating of relative suitability. General form:

$$SPI = P - (CM + CL)$$

where

SPI = Soil Potential Index
P = index of yield or other measure of *performance*, as locally established
CM = index of costs of *corrective measures* to overcome or minimize the effects of soil limitations
CL = index of costs resulting from *continuing limitations*

Notes:

(1) This is not a detailed economic analysis; relative ratings are all that are needed; however, the three indices must be on commensurate scales.

(2) CM and CL must be measured on the same time scale (usually, annual, with present value of future costs used to bring CL to the same scale as CM).

(3) P is a percentage of a locally-established reference yield or performance. It may be >100%.

Key point: the soil *productivity* is balanced against the *costs for corrective measures* and *continuing limitations*. Corrective measures can be one-time, such as land improvements, or continuing, such as fertilization.

3.3.5 The P factor

"P is an index of performance or yield standard for the area. It is established and defined locally." P=100 for a reference soil, usually the best or one of the best soils for the use. Then the expected performance yield for each soil is compared to the standard, and P is established as the percent of standard. P is *not* an actual yield measurement.

For some bizarre reason, *higher* yields are reflected in P, but *lower* yields are reflected in CL. This makes no sense.

Example: if reference yield = 120, then if this soil's yield is 132, P = (132/120)* 100 = 110. If reference yield is 100, then this soil's P = (132/100)*100 = 132.

For non-productive uses (e.g., engineering uses), P = 100 and costs in CM and CL must be normalized to this.

3.3.6 The CM factor

"CM is an index of added costs above a defined standard installation or management system that is commonly used if there are no soil limitations that must be overcome." At this level, CM = 0. It is possible that CM<0 if even the 'standard' installation is not needed in an exceptional case. Examples of installations are drainage systems, or construction of an engineering work such as a septic system.

For each type of added cost, a *point value* is assigned (by a local committee) to each level of costs. These are calibrated such that 1 point of CM is equivalent to 1 point of P. This is relatively easy to establish for productive uses such as crops: if P = 100 represents a gross margin of \$500 ha^{-1}, then 1 point of CM should represent \$5 ha^{-1}.

Example: Corrective measures and their costs for dwellings without basements (from (U.S. Department of Agriculture, 1983b) p. 603-158):

Corrective measures	Costs ($)	CM index
Excavation and grading		
8-15% slopes	100-300	2
15-30% slopes	300-500	4
Rock excavation and disposal (fractured limestone)		
0-8 % slopes	1,000-1,400	12
8-15% slopes	700-900	8
Drainage of footing and slab	600-800	7

From this table we can infer that 1 point of CM = $100, so that if P = 100, the value of a dwelling without basement is $10,000 after the 'normal' costs of construction are taken into account.

An important part of determining CM is the identification of workable technologies and their costs; in the preceding example, which limitations can be corrected (note that no excavation was allowed on slopes over 30%) and their costs.

3.3.7 The CL factor

CM is an indx of limitations that continue after corrective measures (taken into account in CM) have been applied. These are of three types:

1. Continuing *performance*, such as low yield, inconvenience, discomfort, probability of periodic failure (especially of engineering works). This type of continuing limitation should be included in P, not in CL!;

2. Periodic *maintenance costs* to maintain performance, e.g., renewal of a septic systems or periodic maintenance of a drainage system;

3. Off-site *damages* from the use, such as sedimentation or pollution.

The easiest to establish are performance limitations for crops; this is just a ratio of yield reduction to standard yield, i.e., percent reduction in yield. For example, if the standard yield is 120, and a map unit is expected to yield 90 even after all corrective measures have been applied, $CL = (120-90/120)*100 = 25$. This will be subtracted from P (why didn't they just compute it in P to begin with?).

For other expenses, the cost is normalized to P = 100 and usually expressed in present value.

3.3.8 Example rating table

From (U.S. Department of Agriculture, 1983b) p. 603-165:

Soil Use:	Dwellings without basements			Area:	Alpha County		
Mapping Unit:	Calhoun silt loam, A slope			Corrective measures		Continuing limitation	
Evaluation factor	Soil and Site conditions	Degree of limitation	Effects on use	Kind	Index	Kind	Index
Depth to high water table	0-60cm (perched)	severe	wet lawns, construction problems	surface drainage	2	maintain drainage	1
				special drainage during construction	4	yard use restrictions in wet season	6
Flooding	None	slight	None				
Slope	0-1%	slight	None				
Shrink-swell	Low	slight	None				
				Total	6	Total	7

SPR = P - (CM + CL) = 100 - (6 + 7) =87.

3.3.9 Subjectivity in the SPR system

All parts of the system are derived locally, usually in consultation with a variety of rural land users and agents. Thus the actual ratings can be arbitrarily adjusted, however, the soil rankings are less arbitrary, although these can be influenced by the weight given to corrective measures vs. the performance index.

3.3.10 Relation to FAO-style land evaluation

The ‘Land Utilization Type’ is a single, high-technology type, where all possible corrective measures have been applied; then the SPR system estimates whether these were cost-effective and whether there are any continuing limitations.

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