10. Land Evaluation and Land Use Planning

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Abstract:

In order to restore declining trend of qualities of different soils of India, there has been emerging need for soil as well as land evaluation and land use planning. In fact, land evaluation is a pre-requisite for land use planning. This chapter is aimed at correlation of soil survey information, climate, vegetation and other aspects of land with the specific use for which land is evaluated. In this process, the suitability of the land is assessed and classified. Data set requirements for land evaluation are described in relation to Indian context. Updates of different land evaluation approaches like quantitative and qualitative approaches as adopted and practiced in India are briefly described with case studies. For second green revolution, India wants successful adoption of land evaluation and land use planning under strong vision, mission and overall goal. Being the foundation base of production functions, the mode for soil evaluation needs to be shifted in accordance with wide range of objectives. Scientific approaches in quantifying the land evaluation would ensure targeted production of the best suitable crop in a well defined land use planning system. There is further scope to link the land use planning system with supply chain process integrating the farming activities from point of origin i.e. soil and land to the point of consumption i.e. market. India wants prime land, and needs soil based efforts to alleviate poverty through profitable production on sustainable frameworks. Profitable production could be enhanced considerably to ensure even more than double of the farmer's economic growth merely by improving the correctable limitations with a given land.

Keywords: Land evaluation, Land use planning, Soil suitability rating, Prime lands

10.1 Introduction

The demand on the finite land resources is increasing exponentially due to the growing population at the current rate of almost 1.67 per cent. The population growth is leading to unfavorable man to land ratio. In India, per capita cultivable land holding has been declining from 0.5 ha in 1951-52 and reached to 0.14 ha by the year 2000. Although, the food production has increased from 52 m tons (in 1950's) to almost 256 m tons (in 2014), this increase has been largely as a result of expansion in cultivated and irrigated area and high chemical (fertilizer) inputs. The significant growth of agriculture has been at the cost of decline in soil quality and risk of soil degradation. We are now facing the serious threat of ensuring sustainability in our production systems. In many of the so-called first green revolution areas, a whole range of second-generation problems are posing serious challenges to the sustainable agricultural production. About 57 per cent of soils are under different kinds of degradation and these are getting further deteriorated with risk of jeopardizing our food security (Sehgal and Abrol, 1994). In addition to this, many issues concerning environmental sustainability, carrying capacity of our land resources, etc. are also cropping up and adversely affecting soil and human health. These problems demand a systematic appraisal of our soil and climatic resources to recast and implement an effective and appropriate land use plan at regional and local level. The land use or land produce is a subject that tends to ensure profitability. Thus, the concept of land economics is very relevant to make the land use profitable by applying economic principles within the control of farmers by applying the key components of supply chain process beginning from the point of origin (soil) to the point of consumption i.e. market (Mishra 2017).

The purpose of land evaluation is to understand the relationships between the conditions of the land and the manner in which it is utilized. Ideally it should also predict the effects (output) both positive and negative, resulting from the use of land in a particular manner. Land evaluation procedures involve the interpretation of biophysical resource inventories in relation to their use (Sehgal 1993).

Land evaluation has been defined by FAO (1976) 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. The evaluation is a vital link in the chain leading to sustainable management of land resources (Sharma et al. 1994). This includes productive uses such as farming, livestock production and forestry and other uses such as catchments area protection, recreation, tourism and wild life conservation. The land possesses a definite set of capabilities for supporting different crops (Dent and Deshpande 1993). Performance of any crop is largely dependent on soil topography and climatic conditions and the levels of management. It is because of the fact that each plant species requires a different set of conditions for optimum growth, there is a need to evaluate the land resources for sustainable crop growth and to delineate major and efficient crop zones.

10.2 Aims of Land Evaluation

The framework for land evaluation as structured and elaborated by FAO (1976) is the international pillar for reference and is recommended to follow with regional procedures. Land evaluation may be concerned with present land performance and takes into consideration the economics of the proposed enterprises and trade of goods, the social consequences for the people of the area and the region concerned, and the consequences, beneficial or adverse, for the environment. Thus 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 land 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?

The evaluation process does not in itself determine the land use changes that are to be carried out, but provides data on the basis of which such decisions can be taken. To be effective in this role, the output from an evaluation normally gives information on two or more potential forms of use for each area of land, including the consequences, beneficial and adverse effects of each.

10.3 Land Evaluation and Land Use Planning

Land evaluation is part of the process of land use planning. Its precise role varies in different circumstances. It is sufficient to represent the land use planning process by following generalized sequence of activities and decisions:

1. Recognition of a need for change;
2. Identification of aims;
3. Formulation of alternative forms of land use and recognition of their main requirements;
4. Recognition and delineation of the different types of land present in the area;
5. Comparison and evaluation of each type of land for the different uses;
6. Selection of a preferred use for each type of land;
7. Detailed analysis of a selected set of alternatives for distinct parts of the area; this, in certain cases, may take the form of a feasibility study.
8. Decision to implement;
9. Implementation; and
10. Monitoring of the operation.

Land evaluation plays a major part in stages 3, 4 and 5 of the above sequence and contributes information to the subsequent activities. Thus it is preceded by the recognition of the need for some change in the use to which land is put; this may be the development of new productive uses, such as agricultural development schemes, irrigation and flood control dams, forestry plantations, or the provision of services, such as the designation of a national park or recreational area, etc.

The evaluation process itself includes description of a range of promising kinds of uses and the assessment and comparison of these with respect to each type of land identified in the area. This leads to recommendations involving one or a small number of preferred kinds of use. These recommendations can then be used in making decisions on the preferred kinds of land use for each distinct part of the area. Later stages will usually involve further detailed analysis of the preferred uses, followed, if the decision to go ahead is made, by the implementation of the development project or other form of change, and monitoring of the resulting systems.

10.4 Principles of Land evaluation

Certain principles are fundamental to the approach and methods employed in land evaluation. These basic principles are as follows:

1. Land suitability assessment and classification with respect to specified kinds of use
2. Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land
3. A multidisciplinary approach is required
4. Evaluation is made in terms relevance to the physical, economic and social context of the area concerned
5. Suitability refers to use on a sustained basis

6. Evaluation involves comparison of more than a single kind of use

10.5 Land Evaluation Procedures

The land evaluation activities undertaken and the order in which the work is done depend on the type of approach adopted, whether parallel or two-stage.

The main activities in a land evaluation are as follows:

- Initial consultations, concerned with the objectives of the evaluation, and the data and assumptions on which it is to be based
- Description of the kinds of land use to be considered, and establishment of their requirements
- Description of land mapping units, and derivation of land qualities
- Comparison of kinds of land use with the types of land present
- Economic and social analysis
- Land suitability classification (qualitative or quantitative)
- Presentation of the results of the evaluation.

It is important to note that there is an element of iteration, or a cyclic element, in the procedures. Although the various activities are here of necessity described successively, there is in fact a considerable amount of revision to early stages consequent upon findings at later periods. Interim findings might, for example, lead to reconsideration of the kinds of land use to which evaluation is to refer, or to changes in boundaries of the area evaluated.

10.6 Data set requirements for land evaluation

The land units and their homogeneity form the basic requirement for proper land evaluation. The land units selected for land evaluation have no scale limitation. The information on the land units is generated through different kinds of soil surveys.

The land characters and land qualities considered in defining the land units are as under:

Land characters: Land characteristics used in land evaluation are measurable properties of the physical environment directly related to land use and are available from the soil survey. These characteristics are

Bio-physical characteristics: factors like topography (t)-slope length and gradient; Wetness (w)-drainage and flooding

Physical soil characteristics: Texture, soil depth and intensity of acid sulphate layer and gypsum or *kankar* layer

Fertility characteristics (f): Cation exchange capacity of the clay as an expression of weathering stage, Base saturation and Organic matter content

Salinity and alkalinity (n): Salinity status and Alkalinity status

Climatic database: Factors such as temperature, potential evaporation, the temporal and spatial variability of rainfall, specific to an area are considered as database for estimation of growing period.

There are a number of other important properties, which co-vary with changes in the property; however, these properties are of great value in interpreting the various uses. Soil classification systems very much rely extensively on quantitative composition of soils and these compositions are selected on their assumed importance in understanding the genesis of the soil.

Land qualities: It is a complex attribute of land which acts in a distinct manner, its influence on the suitability of land for a specific kind of use. They may be positive or negative. They are in fact practical consequences of land characteristics. They could be segregated in to two groups: FAO (1976) suggests three comprehensive land qualities:

Internal qualities: Water holding capacity; oxygen availability; availability of foot hold to roots; tolerance to iron induced chlorosis; nutrient availability; resistance to structural degradation of top soil; absence of salinity and alkalinity.

External qualities: Correct temperature regime; resistance against erosion; ability for layout of farm plan and workability.

As per the land use, these qualities can be grouped as;

A. **Land qualities related to productivity for crops or other plant growth**: Crop yields; moisture availability; nutrient availability; oxygen availability in root zone; adequacy of foot hold for roots; conditions for germination; workability of the land; salinity and alkalinity; resistance to soil erosion; pests and diseases incidence related to land; flooding hazard; temperature regime; radiation energy and photoperiod; climatic hazard (Wind, hail, frost); air humidity; and drying period for ripening of crops.

B. **Land qualities related to domestic animal productivity**: productivity of grazing land; climatic hardships affecting animals, endemic pests and diseases; nutritive value of grazing land; toxicity of grazing land; resistance to degradation of vegetation; resistance to soil erosion under grazing condition; and availability and quality of drinking water.

C. **Land qualities related to forest productivity**: mean annual increments of timber species; types and qualities of indigenous species; site factors affecting establishment of young trees; pests and diseases; and fire hazards.

D. **Land qualities related to management and inputs:** These qualities may refer to arable use, animal production or forestry. These include trafficability (mechanization); accessibility (laying roads); size of potential managements units; (forest block, farms, fields); and location in relation to markets and supplies of inputs.

The land qualities (both internal and external) are practical consequences on plant growth, performance and producing yield.

10.6.1 Spatial database

(i) Land units

The land unit covers an area of land, usually mapped with specified characteristics, employed as units for land evaluation. Example: major climate, growing period and agro-climatic zones.

- Soil series, soil associations and other soil mapping units.
- Land system and land facets.

Two kinds of land units are employed at different stages, e.g. agro-climatic region-major part of land evaluation at regional level; detailed units-landforms and soils at local level.

Criteria for land units in land evaluation

- Land units should be as homogenous as possible.
- The grouping should have a practical value in relation to proposed land use.
- It should be possible to map the units consistently.
- Should be defined as simply as possible based on properties which are readily observable in the field-soils and land surface.

(ii) Present land use

Current land use in an area is being practiced over the years as per the needs of the people. It has the spatial concept. The present land use or the existing land use is of prime importance in land evaluation. Land evaluation principle emphasizes on the existing land use and its details. It indicates that before considering a particular land unit for evaluation towards alternative land use, it is important to look into the improvements possible in the existing land use through management. Even after the management improvements are made in the present land use, if the expected production levels are not achieved then the evaluation is done for alternative land use.

(iii) Land Utilization Types (LUTs)

Land utilization type is the subdivision of land use which is an important component of land evaluation. Land utilization type deals with specific land use and management.

Produce: The produce of a crop or crop rotation can be sub-divided into four groups such as arable land (annual crops); permanent crops (fruits and tropical perennial crops); grassland and forests.

(iv) Land Use Requirements

Land use requirements are important components in land evaluation since these parameters help in different phenological phases of the crop with a better biomass production. These requirements differ with the type / variety of crop and stage of the crop. Broadly, these land use requirements can be grouped into agro-climatic requirements, soil associated crop requirements, and additional requirements.

In land evaluation, defining the land use requirements is a key issue. For finalizing the land use requirement's criteria specific to a crop/variety/ locality /region, it is necessary to take the help of existing literature, individual's experience, and the experimental data. In the present approach of obtaining crop growth requirements criteria and their ratings, the basis of anticipated yields or experimental yields are also considered. The proper definition of the crop growth requirements needs a good knowledge of the phenology and ecology of the crops/plants under consideration, and requires the input of crop specialists. The procedure of defining the crop growth requirements includes two main phases, respectively linked to the listing of criteria which are of relevance and rating in terms of the optimal and marginal growth conditions. With respect to the identification of criteria, good care should be taken not to duplicate the impact of factors by introducing them at several levels. As such, soil texture affects rooting conditions, aeration and workability, but it should be included only at its most relevant level, e.g. under the rooting conditions.

Agro-climatic crop needs are mainly related to the moisture and energy conditions during the growing season, e.g. during the time that the crop is effectively on the land. It is therefore important to know the length of the growth cycle and of the different phenological stages, and to rate ultimately the optimal and marginal conditions for each of these stages. Requirements in terms of moisture supply depend on the ground-water table and related capillary rise, the soil moisture retention capacity and the evapotranspirative demands. The energy regime is determined by the current temperature, insolation and day-length. Secondary climatic requirements may refer to the sensitivity to extreme levels of air humidity (too high levels promote the development of diseases, particularly in flowering and maturation periods; too low levels may require too high evaporative demands and disruptions in the plant physiological system), extreme temperatures, etc.

Soil-associated crop requirements refer mainly to rooting and aeration conditions, the availability of nutrients and moisture, and the sensitivity or tolerance to toxic elements. Rooting and aeration conditions affect the penetration and development of the plant root system in search for water and nutrients. The soil depth, the texture and/or the eventual presence of coarse fragments in the profile, drainage conditions and flooding hazards mainly influence these qualities. The crop nutrient supply is in the first place determined by the cation exchange capacity and the base status, as expressed per 100 g of soil. In most cases, the sum of bases may be a sufficient parameter to express the total amount of bases available to the plant; for certain crops however, it may also be worthwhile to include additional parameters, such as Ca/Mg or K/Mg ratios as those relations affect directly crop behavior (bananas, oil palm etc). The introduction of pH as a crop parameter is meant to be an expression of the overall base saturation within the soils medium, and to indicate solubility and uptake potential of nutrients in the root zone.

The evaluation of the NPK status in the soil is not a common practice in soil survey reports, but should be promoted. In this respect, minimum and optimal levels of these elements should become a criterion to be taken care of in the evaluation procedures for arable cropping. The sensitivity to specific chemical and other toxic components in the root zone can directly be quantified by the introduction of threshold figures for $CaCO_3$ or gypsum contents in the case of arid zone crops, salinity and alkalinity (expressed through electrical conductivity and ESP values), or sensitivities to exchangeable aluminium for tropical crops. The tolerance to heavy metals may become of steadily increasing importance under conditions where pollution phenomena occur.

Additional requirements related to seedbed preparation and harvesting procedures refer to workability, trafficability and erosion hazards. These depend largely on the combined effects of the soil moisture status (rainfall, groundwater depth, internal drainage, lateral water movement), slope and soil surface characteristics. In terms of management practices, slope and surface properties (stoniness, rockiness) may have an influence on the potential use of machinery for tillage and harvesting and may hence determine the appropriate management system.

Finally, it should be emphasized in term of economical and ecological viability assessment, a number of additional requirements may be added as per local need, it acts as a checklist of requirements to be taken into consideration for land evaluation.

Once the factors affecting crop or land use requirements have been selected and listed, the ratings have to be given to all criteria taken into consideration. If, for example, optimal crop development requires a minimum growth cycle of 180 days, this figure is given the highest rating, and the critical time below which the crop will fail is given the lowest rating. Because the land use requirements are different, factor ratings vary from one crop to another and obviously from one utilization type to another.

Factor ratings are usually expressed in degrees of limitations (or constraints according to the following rating scale (FAO, 1983; Verheye, 1992)

- No limitation or constraint: the specific characteristic is considered (almost) optimal for plant growth;

- Slight limitations: the characteristic/quality is nearly optimal for the given utilization type and affects productivity for not more than 20% with regard to optimal yields;

- Moderate limitations: the characteristic/quality has a moderate influence on the yield decrease, which may reach up to 50-60% of optimal yield; nevertheless, benefits can still be made and the use of the land remains profitable.

In some studies, reference is made to a fifth type of constraint, corresponding to very severe limitations. The difference between a severe and very severe limitation is not considered relevant in the present context, but could become so when a differentiation will be made between correctable and non-correctible types of constraints.

10.6.2 Socio-Economic Data

Socio-economic data of any land unit may not directly influence the land evaluation process. However, the following socio-economic data sets are available, they may help to draw practical conclusions.

I. Management

It covers five aspects such as

- Size of the farms: levels of size used are

- Marginal holding (<1 ha)
- small holding (1-2 ha)
- Semi-medium (2-4 ha)
- medium (4-10 ha)
- large (10 ha and above)

II. Levels of Inputs

For land evaluation, five levels of production inputs are proposed: They are;

a: Low; can in general be borne by the land owners (stone cleaning, simple leveling);
b: Medium: can be borne by the land owner with credit facilities (grading, open drains);
c: High : Govt., funds or long term credit to land owner (simple land reclamation works);

d: Very high : with normal recurring costs and
e: Very high : with high recurring costs where large Govt. funds are required.

III. Labour intensity and availability : Labour; Animal power; labour intensive ; labour extensive

IV. Sources of farm power : Heavy mechanized with crawler tractors; fully mechanized with four wheel tractors ; light mechanization with two wheel or one wheel operated machinery ; animal power ; hand operated tools-man power.

V. The technical know-how of the farmer*:* Low technical knowhow limits the ambitious planning for land use, land management and improvement practices.

- Use of capital and its availability
- Non- recurring requirements or development cost such as land reclamation and installation of irrigation, drainage and erosion structures.

10.7 Land Evaluation Approaches

Land evaluation is the ranking of soil units on the basis of their capabilities (under given circumstances including levels of management and socio-economic conditions) to provide highest returns per unit area and conserving the natural resources for future use (Van Wambeke and Rossiter, 1987). Several systems of land evaluation have been recognized (Storie, 1954; Requier et al., 1970; Sys, 1985; Sehgal et al., 1980). The FAO (1976) panel for land evaluation suggested the classification of land in different categories: Orders, Classes, Sub-classes and Units. The soil-site characteristics are expressed in terms of degree of limitation (0, 1, 2, 3 or 4); the limitation of 2 is considered critical at which the expected yield declined significantly and the cultivation is considered marginally economical. The final soil-site evaluation/suitability is based on the number and degree of limitation (s). Modern approaches involve simulation model predicting yield as a measure of suitability. Although very well refined, yet these approaches are largely based on local experience of farmers or of the researchers.

Since crop performance reflects the integrated effect of the environmental and soil characteristics, it would be appropriate to study the relationships, through regression analysis, between the crop performance and yield-influencing parameters (Gbadegesin & Areola, 1987). In order to construct a knowledge base by which deductive reasoning may lead to ranking of land units, the present attempt is made to interpret the black cotton soils in terms of their characteristics and qualities for developing soil-site suitability models for different crops through a multivariate regression yield model (Sehgal et al.,1989)

The model may need further refinement by having a large number of test sites. The yield and soil-site parameters were compared through a linear equation of the following form based on collected yield data under similar management practices from different locations varying in rainfall and covering the entire black soil region (Table 1).

$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + \mu . . .$

Where :

Y = yield of the crop, q ha^{-1};
X_1 = rainfall, mm;
X_2 = soil depth, cm;
X_3 = growing period, weeks;
X_4 = clay, per cent;
X_5 = calcium carbonate, per cent;
μ = random error;
a = intercept;
b_1 = partial regression coefficient.

In order to find the optimum range of any parameter for crop performance, a quadratic equation was fitted in the following form:

$Y = a + bx + cx^2 + \mu$ . . .

Where :

Y = yield of the crop (q ha^{-1})
X = explanatory variable (rainfall, calcium carbonate)'
μ = random error
a = intercept
b, c = are regression coefficients

The Vertic intergrades (Inceptisols and Entisols) occurring in geographic association with the Vertisols, are mainly cultivated for sorghum and cotton. Yield of sorghum and cotton crops from six experiments and three locations near Nagpur area under similar rainfall pattern were also compared with the soil parameters.

INSERT TABLE 1

Table 1. Relationship of crop performance to soil-site parameters in Vertisols

Name of crop	Number of observations	Intercept	Regression Coefficients					R^2
			X_1	X_2	X_3	X_4	X_5	
Sorghum	15	-14.4091	0.0074* (0.0025)	0.0432 (0.0204)	0.2423* (0.1024)	0.0746 (0.0957)	-0.0606 (0.0923)	0.8505
Cotton	10	-12.0748	0.0172* (0.0045)	-0.0313 (0.0295)	-0.2043 (0.1465)	0.1803 (0.2255)	0.7278* (0.2243)	0.8583
Pigeon pea	12	-4.3625	0.0023* (0.0008)	0.0059 (0.0020)	0.1646* (0.0756)	0.0671 (0.0982)	0.0926 (0.1154)	0.4199

Chick pea	13	4.1164	0.0065* (0.0015)	-0.0478* (0.0291)	-0.0347 (0.0686)	-0.0931 (0.0311)	-0.3878* (0.0735)	0.7515
Pearl millet	8	12.9200	0.0073 (0.0075)	0.0193* (0.0019)	-0.0049 (0.1475)	-0.2310 (0.0917)	-0.0755 (0.0735)	0.9477
Groundnut	9	-8.6524	0.0071 (0.0057)	0.0038 (0.0372)	0.3702* (0.0633)	-0.0093 (0.1179)	0.1089 (0.1047)	0.8181

* : significant at 5% level

X_1 : rainfall (mm)
X_2 : soil depth (cm)
X_3 : growing period (weeks)
X_4 : clay %
X_5 : $CaCO_3$ %
( ) : standard error of variable

Land evaluation involves the assessment of land and soils for their potential for different uses involving matching the land qualities and requirements for the given land use. Both qualitative and quantitative approaches are in vogue.

A. Qualitative evaluation

i) Land capability classification (Klingbiel & Montgomery, 1961).
ii) Land irrigability classification (Soil Survey Staff, 1951; USBR, 1953).
iii) Fertility Capability Classification
iv) Soil suitability classification (FAO, 1976; Sys, 1985; Sys et al. 1993)
v) Prime land classification (Ramamurthy et al.,2012)

B. Quantitative evaluation

i) Soil index rating (Shome and Raychaudhari, 1960; Storie, 1978)
ii) Actual and potential productivity (Riquier et al. 1970)
iii) Soil suitability classification- statistical approach (Sehgal et. al. 1989)
iv) Land use planning and analysis system (LUPAS) (Laborte et.al., 2002):
v) Land suitability assessment by parametric approach (Rabia and Terribile, 2013)
vi) Land suitability by fuzzy AHP and TOPSIS methods (Mukhtar Elaalem et al., 2010)

10.7.1 Land Capability Classification

It is an interpretative grouping of the soils based on inherent soil characteristics, land features and environmental factors that limit land use or impose risk of erosion. Soils are grouped into eight capability classes from I to VIII on the basis of their ability to produce commonly cultivated crops. The classes from I to IV indicate arable and V to VIII indicates non arable lands that can be used for non- agriculture uses. The risk of soil damage progressively increases from Class I to Class VIII. There is a provision to assign sub-class on the basis of kind of predominant hazard, limitation or conservation problem. A sub-class may be further divided into capability units according to similarity in potential and response to management.

While land capability classification system is useful for relatively broad level planning, it needs to be supplemented by more precise evaluation for micro-level planning. Further, the land capability classification is conservation oriented which considers the negative aspects. Yet this system is still widely used because of its simplicity and ease of comprehension. This classification gives general idea about the capability of the soils but does not explain specific crop performance unless supplemented by additional information. This method could be followed effectively for highlighting the conservation- oriented limitations which need immediate attention and for broad grouping of soils into agricultural and non-agricultural lands.

Class: Groups of land units that have the same degree of limitation is denoted as "Class". The risk of soil damage or limitation becomes progressively greater from Class I to Class VIII. The classes show the general suitability of a land unit for agricultural use. Class I to IV- Arable and V to VIII - Non-arable

Sub-classes: These are based on major conservation problems such as: 'e'- Erosion and runoff; 'w'- Excess water or water logging;'s'- Root zone limitation and 'c'- Climatic limitations.

The definitions of the different classes are given in Table 2 and Table 3.

INSERT TABLE 2

Table 2. Principles for the definitions of the arable classes

ARABLE LAND CLASSES				
Parameters	**Class I**	**Class II**	**Class III**	**Class IV**
Definition	Few limitations restrict their use	Moderate limitations	Severe limitations	Very severe limitations
Range of crops	All crops give optimal yields	Most crops give nearly optimal yields	Limited crops don't yield satisfactorily	Yield marginal
Slope Erosion (e)	Level No or low erosion	Gentle slope, Moderate Susceptibility to wind or water erosion	Moderately steep slope Wind and water erosion	Steep slope Very high wind and water erosion
Wetness (w) Flooding / Drainage	Not subject to waterlogging or overflow Well drained	Occasional overflow Moderate Permeability limitation	Frequent overflow Water logging, very slow permeability	Frequent overflow Excessive water logging
Physical soil condition(s)	Hold water well, good	Unfavorable workability,	Low moisture holding	Low moisture <25 cm

	workability Deep (+100 cm)	less ideal depth (50-100 cm)	capacity Shallow depth (25-50 cm)	
Fertility	Well supplied with plant nutrients	Responsive to fertilizers	Low fertility	Low fertility
Salinity and Alkalinity	No or Slight	Slight to moderate easy to correct	Moderate salinity/ sodium hazard	Severe salinity, sodium hazard
Management requirement	Ordinary	Careful management	Very careful	Very careful

INSERT TABLE 3

Table 3. Principles for the definitions of the non-arable classes

Parameters	Pastures		Forest	Recreation and wild life
	Class V	**Class VI**	**Class VII**	**Class VIII**
Definition	**Not suited to cultivation**	**Severe limitations**	**Very severe limitations**	**Unsuitable for any crop**
Range of crops	Pastures	Pasture or range	Woodland	Recreation and wild- life
Slope and Erosion (e)	Nearly level no erosion	Very steep severe erosion	Very steep severe erosion	Erosion hazard
Wetness// (w) Flooding	Frequent overflow	-	-	-
Drainage	Drainage feasible	-	Too wet soils	Too wet soils
Soils (s) conditions	Stony or Rocky	Stoniness, low moisture holding capability. Too shallow	Stoniness. Too shallow	Low moisture holding capacity, stoniness. Too shallow.
Salinity and Alkalinity	-	Severe salinity and sodicity hazard	-	-
Management requirement	Pasture	Pasture	-	-

The disadvantage of this method is that it is (i) highly subjective; (ii) it is a limitation approach, based on one parameter, the land is brought under a lower class.

Martin and Saha (2009) used quantitative land evaluation procedures, namely USDA Land Capability Classification (LCC) and FAO Land Evaluation Procedure for soil site suitability for various land utilization types to assess the land suitability for different crops and for generating cropping pattern for *kharif* and *rabi* seasons in a watershed (Table 4). The database on soil, land use/land cover rainfall, and temperature was generated from data derived from Landsat TM remote sensing satellite and soil survey to perform an integrated analysis in the geographic information system environment. Arable and non-arable lands were delineated in the watershed using the USDA LCC and non-arable areas were masked for removal from future analysis. Different land quality parameters, *viz.*, soil texture, depth, erosion, slope, flooding and coarse fragments under various land units were evaluated for a number of crops. Subsequently all of them were integrated using a sequence of logical operations to generate the land suitability maps for various crops. *Kharif* and *rabi* season cropping patterns were developed by integrating crop suitability maps for the winter and summer seasons separately. Finally, cropping system maps for the watershed were obtained by integrating the two season cropping sequences within the crop calendar. Results indicated that the present agricultural area of 47% could be increased to 71% by adopting scientific land evaluation methods for watershed development. It was also found that better land use options could be implemented in different land units as the conventional land evaluation methods suffer from limitation of spatial analysis for the suitability of various crops.

INSERT TABLE 4

Table 4. Land evaluation based on USDA land capability classification and FAO procedure

Mapping unit	Rabi season				Kharif season			
	Wheat	Mustard	Sugarcane	Suitability	Paddy	Maize	Sugarcane	Suitability
M11	N	N	N	N	N	N	N	N
M12	N	N	N	N	N	N	N	N
P11	S3e	S3e	N	Wheat, mustard	S3e	S3ecf	N	Paddy, maize
P12	S2tse	S3e	S3et	Wheat, mustard, sugarcane	S3e	S2ts	S3et	Paddy, maize, sugarcane
P21	S3t	S2se	S3e	Mustard, wheat	S2tse	S2ts	S3e	Paddy, maize, sugarcane
P22	S3t	S3e	S3e	Mustard, wheat	S2ts	S2tse	S3e	Paddy, maize, sugarcane
T1	S2te	S2te	S2e	Mustard, wheat	S2ts	S2te	S2e	Paddy, maize, sugarcane
T2	N	S3dse	N	Mustard	S3d	S3ds	N	Paddy, maize
AT1	S2d	S2ef	S2ed	Wheat, mustard, sugarcane	S2ds	S2de	N	Paddy, maize, sugarcane
AT2	S2t	S2ef	S2e	Wheat, mustard, sugarcane	S2tse	S2tds	S2e	Paddy, maize, sugarcane

AT3	S2t	S2ef	S2e	Wheat, mustard, sugarcane	S2tse	S2tds	S2e	Paddy, maize, sugarcane

e, Erosion; cf, Coarse fragments; t, Texture; d, Drainage; s, Slope; f, Flooding and N, Not suitable.

10.7.2 Land Irrigability Classification

In this system (USBR 1953), soils are first categorized according to physical factors (topography, drainage and water quality) and socio-economic factors (location and size of farms, characteristics of land ownership, cultural patterns, and the skill and resources of individual operators development costs, etc.). Separation of land irrigability classes is made on specified limits of soil properties and other physical parameters. Land irrigability system may be used for selection of irrigable lands, estimation of water requirements, development costs and benefits from irrigation. Such information will help in land use planning decisions. Soil Survey and Land Use Planning Scheme, Sabour in Bihar also used similar classification (Singh and Mishra 1997, Singh et al 1996).

This system also provides six suitability classes (Table 5) for irrigation based on the soil and land characteristics and the repayment capacity. The sub-classes provided are based on deficiencies or problems with respect to topography (t), soil (s), and drainage (w).

- Soils are categorized based on their suitability for sustained use under irrigation.
- Physical factors (topography, drainage and water quantity).
- Socio-economic factors

Subclass: Groups of land units with some dominant limitations like soil (s), topography (t), and drainage (d).

Irrigability units: Grouping of lands that are nearly alike in suitability for irrigation.

INSERT TABLE 5

Table 5. Characteristics of land irrigability classification

Class	**1**	**2**	**3**	**4**	**5**	**6**
Arability	Arable	Arable	Arable	Limited Arable	Temporarily Non-Arable	Non-Arable
Repayment capacity	High	Intermediate	Intermediate	Low	-	Not repayable
Crop suitability	Wide	Restricted	Restricted	Few Specific crops	Not suitable	Not suitable
Yield	High and sustained	Moderate and sustained	Moderate and sustained	Low	Very low	Extremely low
Water use	Efficient	Moderately efficient	Moderately efficient	Little efficient	Very low efficient	Inefficient
Physical Parameters						
Slope %	<1	1-3	3-5	5-10	>10	>10
Soil depth (cm)	>90	45-90	22.5-45.0	7.5-22.5	<7.5	<7.5
Permeability (mm/hr)	5.0-50	50-130	130-250	>250	>250	>250

Texture	Sandy loam, clay loam	Sandy loam, sandy clay loam	Clay, loamy sand	Sandy, clay	Any	Any
WHC (cm)	12	9-12	6-9	2-6	<2	<2

10.7.3 Land Suitability Classification

Land suitability classification refers to the fitness of a given type of land for a defined use. This classification is arrived at on the basis of soil survey information, economic and social analysis, kinds of land use and need for change. Separate classifications are made with respect to each kind of land use that appears to be relevant for the area (FAO, 1976). The land evaluation proposed by FAO (1976) defines the basic concepts and principles followed universally. The basic concepts include the land and its major use, utilization type, characteristics, qualities and diagnostic criteria. Land includes soil, vegetation, hydrology, landform and climate. The framework suggested classification of land into different categories. viz., orders, classes, subclasses and units. There are two orders namely S for suitable lands and N for non-suitable lands; further three classes (S1,S2,S3) within the order S and two classes (N1,N2) under the order N depending on degree of limitations with respect to specific land use. The appraisal of the classes, within the order is done according to the land limitations. The subclasses reflect the kind of limitations that are the major kinds of improvement measures required within these classes. They are indicated by the symbols using lower case letter following the Arabic numeral.

In the land evaluation, there are four steps namely (i) characterization of existing soil, climatic and land use conditions (ii) development of soil site criteria or crop requirements (iii) matching of crop requirements with existing soil and climatic conditions and (iv) choosing of the best fit among the crops and the selecting the same as the alternative crop strategy.

Among the above four steps, the formulation of the soil site criteria to meet the crop requirements forms a vital and important step. For the development of crop requirements, one has to do either experimentation at each well characterized growing environment or take the help of published literature. Naidu et al. (2006) have compiled the soil-site requirement of major crops of India by reviewing published literature and consulting crop specific researcher teams.

Matching of crop requirements consists of comparing existing climate, soil and physiographic conditions with the soil-site criteria with respect to individual crop. On the basis of the degree and the number of limitations identified, the suitability class is established, *viz*., highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable land (N1 & N2) for specific kind of land use. The S1 classes correspond to areas, which have a yield potential above 80% of the maximal attainable harvest within the climatic region of the area. This figure drops to 60% and 40% for classes S2, and S3, respectively.

An ideal method to decide adoption of a cropping pattern (land use) on a particular soil unit is to have prior knowledge of the yield performance. Yields are the integrated end products of interactive processes of all factors and inputs and are, therefore, the best indices of productivity potentials. It is neither possible to obtain such information for all soil units in all the areas in view of the cost, nor it is necessary. Soil survey and classification aid in transfer of technology and, therefore, form the basis for evolving rational land use and management methods. Analysis of crop yields obtained by farmers over the years in relation to management levels on known soils (soil series) in surveyed area or field experimental data should help in deciding cropping pattern and transfer of technology to similar areas.

The land suitability can be determined by three methods.

(i) Simple limitation method
(ii) Limitation method with criteria of number and intensity of limitation.
(iii) Parametric method

(i) Simple limitation method: In this limitation method, the suitability classes and sub-classes are directly assigned to land units based on suitability criteria.

In this method with criteria of number and intensity of limitation, the first step is to assign the limitation to each of the parameter.

0 – no limitation
1 – slight limitation
2 – moderate limitation
3 – severe limitation
4 – very severe

(ii) Based on number and intensity of limitations, classes are assigned.

S1 – Very suitable → 3 or 4 slight limitation
S2 – Moderately suitable →More than 3 or 4 slight limitation
S3 – Marginally suitable → 2 or 3 moderate or one or more severe limitation
N1 – Actually unsuitable, but potentially suitable
N2 – Unsuitable

(iii) Parametric method: This method suggests the calculation of productivity index (Riquier et.al., 1970) considering nine factors viz., moisture (H), drainage (D), effective depth (P), texture/structure (T), base saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity/nature of clay (A) and mineral reserve (M). Each of the above parameters is given numerical value between 1 to 100 and resultant index obtained by a multiplication of nine factors are positioned in one of the five different classes.

Productivity Index=H x D x P x T x N/S x O x A x M

Based on overall rating by multiplicative method, classes are assigned as under:

S 1 : 100 – 75
S2 : 75 – 50
S3 : 50 – 25
N1 : 25 – 12
N2 : 12 – 0

Under each method, the suitability of the soil units for soybean is assessed and presented in Tables 6, 7, 8 and 9. Similar method was extensively used elsewhere (Singh and Mishra 1995, 1996).

INSERT TABLE 6

INSERT TABLE 7

INSERT TABLE 8

INSERT TABLE 9

Table 6. Climatic and soil-site suitability criteria for soybean

Land use requirement			**Rating**			
Soil-site characteristics						
		Unit	**Highly suitable S1**	**Moderately suitable S2**	**Marginally suitable S3**	**Not suitable N**
Climatic regime	Mean temperature in growing season	°C	25-28	29-32	33-36	>36
	Mean RH in growing season	%	70-75	60-65	50-60	<50
	Total rainfall	mm	600-750	500-600	400-500	<400
Land quality						
Moisture availability	Length of growing period	Days	>120	100-120	85-100	<85
	AWC	mm/m	>200	150-200	150-50	
Oxygen availability to roots	Soil drainage	Class	Well drained	Moderately well drained	Poorly drained to imperfectly drained	
Nutrient availability	Texture	Class	cl, scl, l, sil	sl, c, sic, sicl	c+ (SS), ls	s
	pH	1:2.5	6.5-7.5	7.6-8.5 6.4-6.0	>8.5	
	OC	%	Medium	High	Low	
Rooting conditions	Effective soil depth	cm	>75	50-75	50-25	<25
	Stoniness	%	>15	15-25	25-35	
	Coarse fragments	Vol %				
Soil toxicity	Salinity (EC saturation extract)	dS/m	<1.0	1-2	2 to 4	>4
	Sodicity (ESP)	%	<5	5-10	10-15	>15
Erosion hazard	Slope	%	<3	3.5	5-8	>8

Table 7. Land Suitability Classification for Soybean by Simple Limitation Method

Soil units	**AmB**	**AmB2**	**AmC2**	**Af B**	**Af B2**	**Bm B2**	**CmC2**	**DmB**	**DmB2**	**DmC2**	**Dk B2**
Climatic characters											
Total Rain (mm)	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3
Rainfall during growing period	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2
LGP	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1
Mean temp. GP	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1
Site Characteristics											
Slope %	S_1	S_1	S_2	S_1	S_1	S_1	S_2	S_1	S_1	S_2	S_1
Drainage	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1
AWC	S_1	S_1	S_1	S_1	S_1	S_3	S_1	S_1	S_1	S_1	S_1
Soil characters											
Texture	S_2	S_2	S_2	S_1	S_1	S_2	S_2	S_2	S_2	S_2	S_2
Depth	S_1	S_1	S_1	S_1	S_1	S_3	S_2	S_1	S_1	S_1	S_1
pH	S_2	S_2	S_2	S_2	S_2	S_1	S_3	S_2	S_2	S_2	S_2
EC	S_1	S_1	S_1	S_1	S_1	S_3	S_1	S_1	S_1	S_1	S_1
ESP	S_1	S_1	S_1	S_1	S_1	S_3	-	S_1	S_1	S_1	S_1
Suitability class	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3

Table 8. Land Suitability Classification for Soybean based on number and intensity of limitations

Soil units	**AmB**	**AmB2**	**AmC2**	**AfB**	**AfB2**	**BmB2**	**CmC2**	**DmB**	**DmB2**	**DmC2**	**DkB2**
Total Rainfall	3	3	3	3	3	3	3	3	3	3	3
Rainfall during growing period	2	2	2	2	2	2	2	2	2	2	2
GP	0	0	0	0	0	0	0	0	0	0	0
Mean temp. GP	0	0	0	0	0	0	0	0	0	0	0
Site Characteristics											
Slope (%)	1	1	2	1	1	1	2	1	1	2	1
Drainage	1	1	1	1	1	1	1	1	1	1	1
AWC	0	0	0	0	0	3	1	0	0	0	0
Soil											
Texture	2	2	2	2	2	2	2	2	2	2	2
Depth	0	0	0	0	0	3	2	0	0	0	0
Soil fertility											
pH	2	2	2	2	2	2	3	2	2	2	2
EC	0	0	0	0	0	0	1	0	0	0	0
ESP	1	1	1	1	1	1	4	1	1	1	1
Suitability class	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_3

Table 9. Land Suitability Classification for Soybean by Parametric Method

Soil unit	**AmB**	**AmB2**	**AmC2**	**AfB**	**AfB2**	**BmB2**	**CmC2**	**DmB**	**DmB2**	**DmC2**	**DkB2**
Climatic											
Total Rainfall	50	50	50	50	50	50	50	50	50	50	50
Rainfall during growing period	50	50	50	50	50	50	50	50	50	50	50
LGP	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5
Mean temp. GP	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5	97.5
Site Characteristics											
Slope	90	90	72.5	90	90	90	72.5	90	90	72.5	90
Drainage	90	90	90	90	90	90	90	90	90	90	90
AWC (mm/m)	97.5	97.5	97.5	97.5	97.5	50	90	97.5	97.5	97.5	97.5
Soil											
Texture	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
Depth	97.5	97.5	97.5	97.5	97.5	50	72.5	97.5	97.5	97.5	97.5
Fertility											
pH	72.5	72.5	72.5	72.5	72.5	72.5	50	72.5	72.5	72.5	72.5
EC	97.5	97.5	97.5	97.5	97.5	97.5	90	97.5	97.5	97.5	97.5
ESP	90	90	90	90	90	90	20	90	90	90	90
Overall suitability class	8.4	8.4	6.8	8.4	8.4	2.2	0.66	8.4	8.4	6.8	8.4
	N_2	N_2	N_2	N_2	N_2	N_2	N_2	N_2	N_2	N_2	N_2

10.7.4 Fertility Capability Classification

The soil survey report provides information on the relative suitability of soils for alternative uses, however, its utility can be enhanced if the taxonomic units are grouped into management units which can easily indicate the potentials and constraints of an area in terms of its fertility, tillage and irrigation management. The Fertility Capability Classification (FCC) system is a technical soil classification system that focuses quantitatively on the physical and chemical properties of the soil that are important to soil fertility management (Buol, et al., 1975). The FCC lays maximum emphasis on the component of soil fertility within 50 cm layer from the surface, however soil taxonomy puts more emphasis on sub-surface soil properties because of their more permanent nature.

The system consists of three categorical levels '**type**' (texture of plough layer or surface 20 cm) at the highest category.

S = Sandy top soils : loamy sands and sands (by USDA definition)

L = Loamy top soils : <35% clay but not loamy sand or sand

C = Clayey top soils : >35% clay

O = Organic soils : >30% O.M. to a depth of 50 cm or more

The **substrata type**, which is the next lower category of the system, refers to the texture of the sub-soil that occurs within 50 cm from the surface and is used only when there is any marked textural change from the surface or if a hard root restricting layer is encountered within 50 cm. The substrata types are as follows:

S = Sandy sub soils: 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

R = Weathered parent material (murrum) as proposed by Jagdish Prasad (2000)

Modifiers: Condition modifier is the lowest category of FCC system, which is determined after assessing the physical and chemical properties of the surface and sub-surface soils. Where more than one criterion is listed for each modifier, only one need to be met. The criterion listed first is the most desirable one and should be used if data are available. Subsequent criteria are presented for use where data are limited.

Water logging (g)	=	(gley) : soil or mottles with < 2 chroma within 60 cm of the soil surface and below all A horizons, or soil saturated with water for > 60 days in most years;
Soil moisture stress (d)	=	(dry) : ustic, aridic or xeric soil moisture regimes (subsoil dry > 90 cumulative days per year within 20-60 cm depth);
Low cation exchange	=	(low cation exchange capacity) : applies only to plow layer or surface

capacity (e)		20 cm, whichever is shallower : CEC < 4 meq./100 g soil by Σ bases + KCl-extractable Al (effective CEC), or CEC < 7 meq/100 g soil by Σ cations at pH 7, or CEC <10 meq./100 g soil by ∑ cations + Al + H at pH 8.2;
Aluminum toxicity (a)	=	(aluminum toxicity) : >60% Al-saturation of the effective CEC within 50 cm of the soil surface, or > 67% acidity saturation of CEC by Σ cations at pH 7 within 50 cm of the soil surface, or >86% acidity saturation of CEC by Σ cations at pH 8.2 within 50 cm of the soil surface or pH <5.0 in 1:1 H_2O within 50 cm, except in organic soils where pH must be less than 4.7;
Acidity (h)	=	(acid) :10-60% Al-saturation of the effective CEC within 50 cm of soil surface, or pH in 1:1 H_2O between 5.0 and 6.0;
High P-fixation by iron (i)	=	(high P-fixation by iron):% free Fe2O3 to % clay > 0.15 and more than 35% clay, or hues of 7.5 YR or redder and granular structure. This modifier is used only in clay types; it applies only to plow-layer or surface 20 cm of soil surface, whichever is shallower;
Amorphous clays (x)	=	(X-ray amorphous) : pH >10 in 1N NaF, or positive to field NaF test, or other indirect evidences of allophane dominance in the clay fractions;
Low nutrient reserves (k)	=	(low K reserves): <10% weatherable minerals in silt and sand fraction within 50 cm of the soil surface, or exchangeable K<0.20 meq./100 g, or K<2% of Σ bases; if bases <10 meq/100 g;
Calcareousness (b)	=	(basic reaction) : free $CaCO_3$ within 50 cm of soil surface (effervescence with HCl), or pH>7.3;
Salinity (s)	=	(salinity):>4 S m^{-1} ^{o}f electrical conductivity of saturated extract at 25C within 1 m of the soil surface;
Alkalinity (n)	=	(natric):>15% Na-saturation of CEC within 50 cm of the soil surface;
Sulphides (c)	=	(cat clay) : pH in 1:1 H_2O is <3.5 after drying and jarosite mottles with hues of 2.5 Y or yellower and chroma 6 or more are present within 60 cm of the soil surface;
Gravel (r)	=	(gravel): a prime (‘) denotes 15-35% gravel or coarser (>2 mm) particles by volume to any type or substrata type texture (example : S’L = gravelly, sand over loamy; SL’ = sandy over gravelly loam); two prime marks (“) denote more than 35% gravel or coarser particles (>2mm) by volume in any type or substrata type (example : LC” = loamy over clayey skeletal; L’C” = gravelly loam over clayey skeletal);
Slope (s)	=	(slope) : where it is desirable to show slope with the FCC, the slope range percentage can be placed in parenthesis after the last condition modifier (example : Sb (1-6%) = uniformly sandy soil calcareous in reaction, 1-6% slope.

Management measures to overcome the limitations

Waterlogging (g)	=	Denitrification frequently occurs in anaerobic subsoil; tillage operations and growth of certain crops may be adversely affected by excess rain unless tilling or other drainage procedures improve drainage; good soil moisture regime for rice production.
Soil moisture stress (d)	=	Moisture is limiting during the dry season unless soil is irrigated; planting date should take into account the flush of N at onset of rains; germination problems are often experienced if first rains are sporadic.
High leaching potential	=	Low ability to retain nutrients against leaching, mainly K, Ca and Mg; heavy applications of these nutrients and of N fertilizers should be split; potential danger of over liming.
Aluminium toxicity (a)	=	Plants sensitive to Al-toxicity will be affected unless lime is applied; extraction of soil water below the depth of lime incorporation will be restricted; lime requirements are high unless a modifier is also indicated; this modifier is desirable for rapid dissolution of phosphate rocks and for good latex flow in rubber; Mn-toxicity may occur in some of these soils.
Acidity (h)	=	Low to medium soil acidity; requires liming for Al-sensitive crops, such as cotton and alfalfa.
High P fixation (i)	=	High P fixation capacity; requires high levels of P fertilizer or special P management practices; sources and methods of P fertilizer application should be considered carefully; with C texture, these soils have granular soil structure.
Amorphous clays (x)	=	High P-fixation capacity; amount and most convenient source of P to be determined; low organic N mineralization rates.
Vertic character (v)	=	Clayey textured topsoil with shrink and swell properties; tillage is difficult when too dry or too moist, but soils can be highly productive; P deficiency common.
Low nutrient reserves	=	Low ability to supply K; availability of K should be monitored and K fertilizers may be required frequently; potential K-Mg-Ca imbalances.
Calcareousness (b)	=	Calcareous soils; rock phosphate and other non-water-soluble phosphates should be avoided; potential deficiency of certain micronutrients; principally iron and zinc.
Salinity (s)	=	Presence of soluble salts; requires drainage and special management for salt-sensitive crops or the use of salt-tolerant species and cultivars.
Alkalinity (n)	=	High levels of sodium; requires special soil management practices for alkaline soils, including use of gypsum amendments and drainage.
Sulphides (c)	=	Potential acid sulfate soil; drainage is not recommended without special practices; should be managed with plants tolerant to high water table level.

How to arrive at FCC Units

The soil is first classified based on the presence or absence of soil constraints. Most of the quantitative limits used in FCC are the criteria already used in the soil. Types and substrata types are represented in capital letters, modifier in the lower case as prime and slope are in the parenthesis

For example: In typical Ultisols, the FCC unit "Lcaei" indicates

L Loamy surface texture
c Clayey sub soil texture
a Aluminium toxicity
e Low CEC
i High P fixation by iron

Mathan et al. (1994) studied 21 soils of Kamarajar district of Tamil Nadu state and grouped into 8 FCC units based on type, substrata type and conditional modifiers. These FCC units can be used for conducting fertility based experiments. The condition modifiers identified are 'd', 'b', 'm', 'v', 'm', 'n', 'k', 'i' and 'e', whereas in acid soils of Nilgiris district, condition modifiers observed are 'a', 'h', 'i', and 'e' (Mathan, 1990). Additionally, as a local modifier, Mg (m) deficiency was identified.

10.7.5 Prime Lands Classification

Heterogeneity is a basic characteristic of lands and this heterogeneity means the capacity of lands to support various functions simultaneously. Land use is the key activity which determines the performance of lands such as land based production, infrastructure and housing (Wiggering et al. 2003). The recent trend in land use in some areas resulted in loss of some prime farm lands to industrial and urban uses (Sturdevant et al. 2001). The loss of prime farm lands to other uses puts pressure on marginal lands which generally are more fragile, erodible, less productive and cannot be easily cultivated. The significant reduction in the area under culturable waste lands indicates clearly the conversion of even marginal lands for agricultural purposes. The multi-functionality of crop production system refers to the fact that crop production activity is not limited to produce food and fibre and may also have other functions. For that purpose, land has been classified into different classes according to their potential for raising crops or other purposes. According to USDA, prime farm lands are defined as lands that have the best combination of physical and chemical characteristics for producing food, feed, fiber, forage, oilseed, and other agricultural crops with minimum inputs of fuel, fertilizer, pesticides and labour, with tolerable soil erosion. It has the combination of favorable soil properties, growing season, and moisture supply needed to produce sustained high yields of crops in an economic manner if it is treated and managed according to acceptable farming methods. The classification will identify the potential to use a given piece of land for different purposes, based on bio-physical limitations of the land such as soils, climate and topography that cannot be removed or improved by acceptable level of management. Land with higher capability has more options for use and also likely to have reasonable resilience to adaptation *vis a vis* climate change. Further, climatic constraints also have equal importance for land capability classification by restricting plant growth rate, ploughing, sowing and harvesting. Procedure and criteria given by Read (1988) and Giles and Koeln (1983) for classification of prime lands in Mysore district has been suitably modified (Table 7.9) by considering landform, soil depth, gravelliness, erosion, LGP and productivity of crops (Ramamurthy et al., 2012).

Methodology followed to delineate Prime Irrigated Lands (PIL), Prime Rainfed Lands (PRL) and Marginal Lands (ML) is presented in Table 10 and Figure 1 and Prime lands map of Mysore district of Karnataka is presented in Figure 2.

INSERT TABLE 10

Table 10. Criteria used in delineation of prime lands

Particulars	**Prime irrigated**	**Prime rainfed**	**Marginal lands**
	Indicators		
Soil depth	-	>50 cm	<50 cm
Landform	-	Level to gently sloping	Moderate to Highly sloping lands
Gravelliness	Non gravelly	Non gravelly to slightly gravelly	Gravelly
Length of growing period	-	>120 days	<120 days
Erosion	-	Nil to slight	Moderate to severe
Productivity of crops	<30% deviation from attainable yield	<30% deviation from attainable yield	>30% deviation from attainable yield

INSERT FIGURE 1

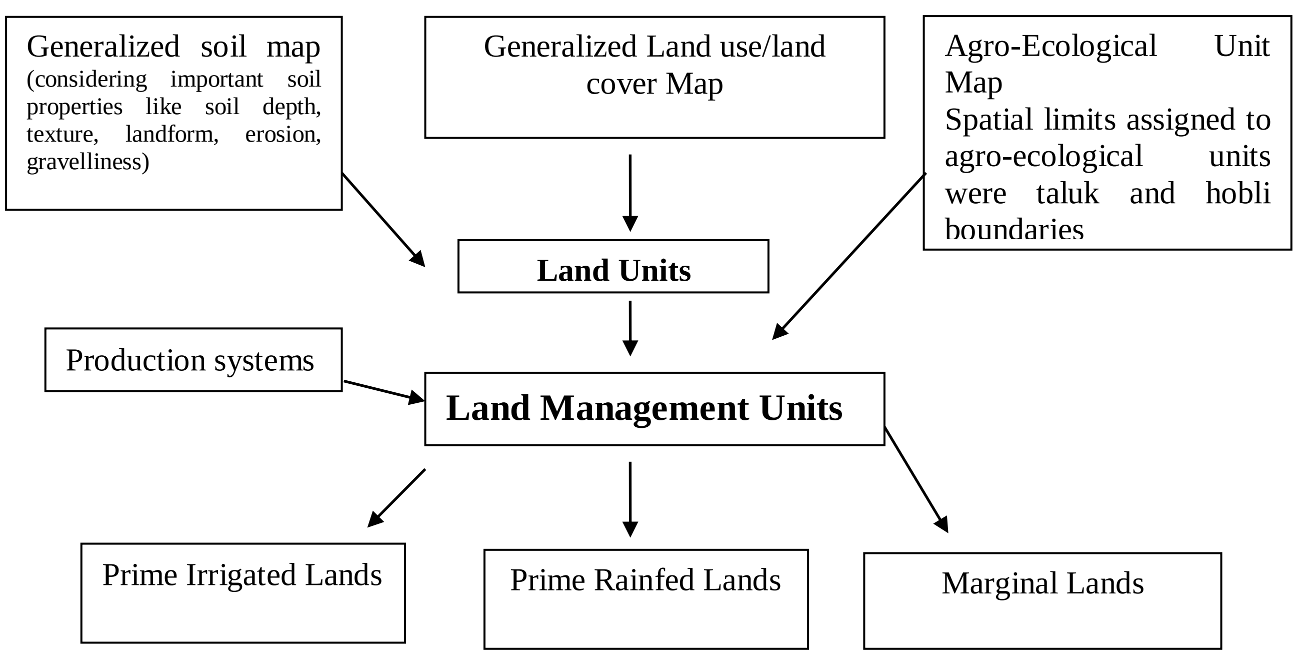

Fig. 1. Methodology followed for delineation of Prime Agricultural Land

INSERT FIGURE 2

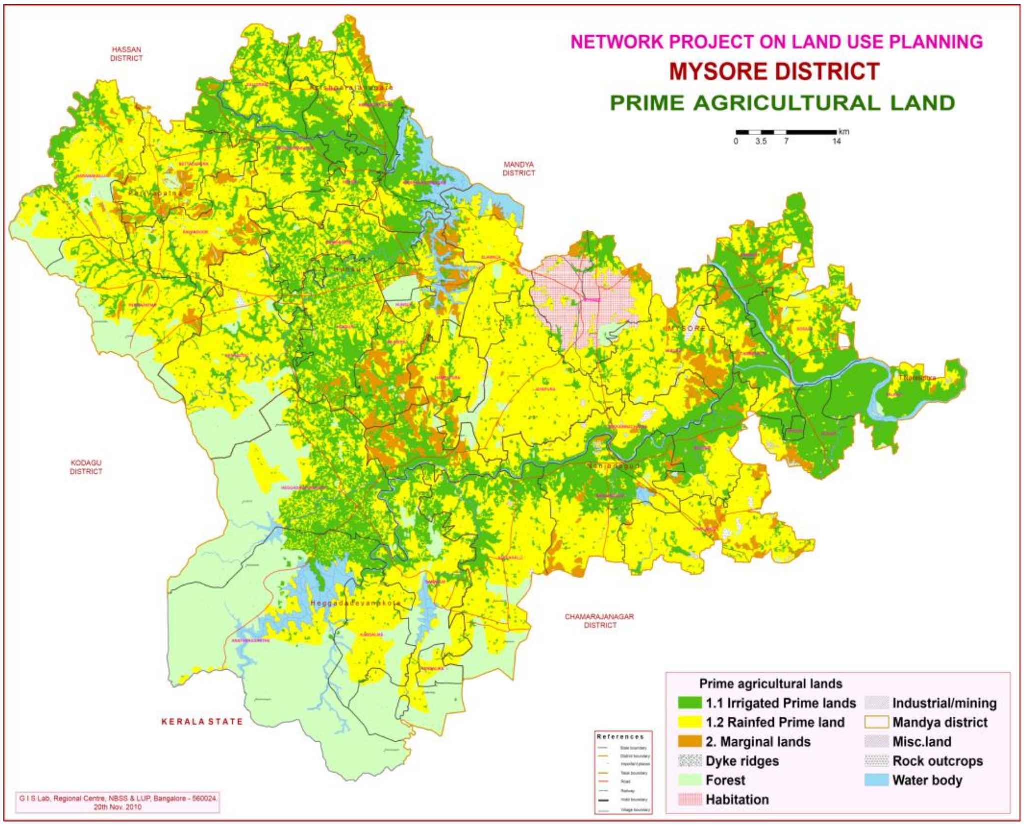

Fig. 2. Prime agricultural lands in Mysore district

Distribution and per cent area under prime irrigated, rainfed and marginal lands in different *taluks* is presented in Table 11.

INSERT TABLE 11

Table 11. Area under different categories of prime lands in Mysore district

Taluks	**Per cent area**		
	Prime Irrigated Lands	**Prime Rainfed Lands**	**Marginal Lands**
H.D.Kote	4.25	6.91	0.63
Hunsur	4.50	6.46	0.95
K.R.Nagar	4.81	3.50	0.14
Mysore	1.27	7.70	0.68
Nanjanagud	4.24	8.71	0.74
Piriyapatna	2.08	7.77	0.91
T.Narsipura	5.72	2.47	0.41

T. Narsipura *taluk* has the highest prime irrigated lands followed by K.R Nagar and Hunsur. Minimal prime irrigated lands are in Piriyapatna *taluk*. Nanjangud *taluk* has the highest prime rainfed area followed by Piriyapatna, Mysore, H.D.Kote and Hunsur *taluks*. There is a need for government agencies to consider the potentials of land before earmarking land for other than agricultural uses. Hunsur and Piriyapatna *taluks* have comparatively more marginal lands, which can be diverted to non-agricultural uses.

10.7.6 Storie Index Rating

Soil evaluation is the determination of productivity ratings, which is defined as capacity of the soil to produce crops. Soil texture, climate, soil management, drainage, soil salinity or alkalinity, nutrient status is some of the important factors that govern the productivity of the soil. Storie (1950) used the four parameters for evaluation of soil productivity. It is a parametric approach. Parameters are not based on requirement of any crop, only soil and site characteristics are taken in to consideration.

Four groups of factors are considered.

SIR = A·B·C· X or D

A = Cracter of soil profile
B = Texture of surface soil
C=Slope
X or D = Miscellaneous

Ratings are given based on the soil parameters and overall rating is calculated by the multiplicative method. Based on this rating the classes are allotted.

Ratings	Grade	**Class**
80 –100	1	Excellent
60 – 79	2	Good
40 – 59	3	Fair
20 – 39	4	Poor
10 – 19	5	V. Poor
0 - 9	6	Not suitable

Shome and Raychoudhuri (1960) by using three soil parameters viz. A-soil profile characteristics; B-topography, texture and structure and C-degree of climate suitability, salinity, stoniness and tendency to erode and assessed soils of 294 Indian districts by using soil index rating. They concluded that soil index rating is a permanent feature of the soil, whereas Storie's productivity ratings can be varied by adopting more and more improved management practices.

10.7.7 Actual and Potential Productivity

The earliest approach in soil productivity indices and rating was initiated by Shome and Raychoudhuri (1960). Later on, Riquier et al. (1970) have evolved a system of soil appraisal in terms of actual and potential productivity. It is a modified version of Storie's Index. Nine factors *viz*. moisture, drainage, depth, texture, base saturation, soluble salts, organic matter, CEC and mineral reserves are rated on a scale 0-100 and the percentages cumulatively multiplied to obtain Productivity Index (P). In a similar manner, the Potentiality Index (P') is calculated after effecting the management measures. The ratio P: P' indicating the extent to which productivity can be improved is called the co-efficient of improvement. Soils with rating index 65-100 are excellent, 35-64 good, 20-34 average, 8-10 poor and below 8 extremely poor. Maps showing productivity and potentiality index can also be prepared. It is evident that the land evaluation system of Riquier et al. (1970) does not explain the variability in the yield. Like Storie Index, this system of land evaluation has the limitation in that one limiting factor reduces the Index of Productivity. Also, assigning values to factors like drainage is difficult. Perhaps, factors should be chosen according to the operating limitations affecting the crop growth within a particular region to obtain a more realistic productivity rating. However, there is need to improve this technique under diversified Indian conditions for reliable applications (Mishra 2015, 2017).

Naidu et al. (1986) assessed productivity and potentiality of eight extensively occurring soil series of Delhi (UT) through Riquier's method. Out of these eight series, three were graded as good class and another three series graded as average and while two were graded as poor class due to their inherent physico-chemical limitations. It was observed that soil texture and moisture properties are the prime factors which influenced the productivity and potentiality ratings. Vishalakshi Devi and Naidu (2016) evaluated major sugarcane growing soils of Chittoor district of Andhra Pradesh by using qualitative and quantitative methods. The qualitative method employed were USDA land capability classification and land suitability classification, while the quantitative evaluation method includes Riquier's parametric approach. The soils of study area were classified into land capability classes IV, V and VI. However, the land suitability evaluation suggested that these sugarcane growing soils were moderate to marginally suitable for growing sugarcane crop. Riquier's parametric approach was found to be good indicator for identification of production potential of sugarcane growing soils. The land evaluation study revealed that, characteristics and suitability of these soils for sugarcane crop were highly variable, hence their management must be site specific. Singh and Mishra (1996, 1997), Singh et al. (1996) and Mishra (2016) applied Riquier's procedure for soil evaluation in Bihar.

Mishra (2016) quantified the extent of potential productivity through improvement in Kosi zone of Bihar. The Soil Survey and Land Use Planning Scheme, Sabour in collaboration with NBSS and LUP, Regional Centre, Kolkata has established altogether 10 soil series in Kosi zone with their land capability and irrigability sub-classes (Table 12 and 13). The soil series is a group of soil horizons, similar in differentiating characteristics and arrangement within the series control section, except for the surface soil, have developed under comparable climatic and geomorphic environments, and is a key to any landscape unit.

INSERT TABLE 12

Table 12. Agroclimatic zone II: Location, area, districts and major land use choice

AC Zone II	Latitudes	Longitudes	Total geographical area (mha)	Net sown area (mha)	Main crop grown	Districts
North-east alluvial plain	$25^0$10'-$26^0$32'N	$86^0$21'-$88^0$19'E	2.08	1.21	Rice, wheat, maize, jute, moong, millets, sugarcane, kalai, barley, potato, grasses, vegetables, oilseeds and spices	Purnea, Katihar, Saharsa, Supaul, Madhepura, Araria and Kisanganj

INSERT TABLE 13

Table 13. Soil Series established in Kosi region of Bihar

Physiographic region	Soil series	Soil Taxonomy	Land capability subclass	Irrigability sub class	Land use pattern (Major)
Indo-Gangetic alluvial plain *(Alluvial cone of Kosi river)* **Saharsa, Madhepura, Supaul, Araria & Purnia districts**	Arraha	Typic Ustifluvent	IIw	2d	Rice, gram & khesari
	Baruari	Typic Psammaquents	IVws	3ds	Rice
	Bhargaon	Aeric Fluvaquents	IIIws	3ds	Rice, wheat & mustard
	Hanuman nagar	Typic Ustipassements	IVws	3ds	Rice & potato
	Keskata	Aeric Endoaquents	IIIsw	3sd	Rice, wheat & linseed
	Madhipura	Typic Ustifluvents	IIIs	3s	Rice & mustard
	Madhuban	Aeric Fluvaquents	IIIws	3d	Rice & Khesari
	Nirpur	Aeric Endoaquepts	IIw	2d	Rice & lentil
	Paina	Typic Haplustepts	IIIw	3d	Rice, wheat & Khesari
	Tikapatti	Aeric Endoaquents	IIIw	3d	Rice, wheat & Khesari

Actual and potential productivity for 10 soil series computed following the methods outlined by Riquier and associates in 1970. It is apparent that proper management/improvement of soils could enhance the productivity even up to 1.34 to 1.77 times (Coefficient of improvement), although such figures (Table 14 and 15) could further be authenticated with agronomic yields. However, there is need of refinement of this technique so that productivity of a soil could be computerized/ authenticated.

INSERT TABLE 14

Table 14. Actual soil productivity levels with associated parameters

Parameter	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6	Series 7	Series 8	Series 9	Series 10
Moisture (H)	H4c	H3c	H4c	H4c	H4c	H4c	H4c	H4c	H4c	H4c

Drainage (D)	D2a	D2a	D2a	D2a	D3a	D2a	D2a	D2a	D2a	D2a
Depth (P)	T6	T2	T4	T4	T4	T4	T6	T6	T6	T6
Base saturation (N)	N5	N5	N5	N5	N5	N5	N5	N5	N5	N5
Salinity (S)	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Organic matter (O)	O1	O1	O1	O1	O1	O1	O1	O1	O1	O1
Clay CEC, cmolkg^{-1}(A)	A0	A0	A0	A0	A0	A0	A0	A0	A0	A0
Mineral reserve (M)	M1	M1	M1	M1	M1	M1	M1	M1	M1	M1
Parent material	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
Permeability	Moderate	Rapid	Moderate	Rapid	Rapid	Rapid	Slow	Slow	Slow	Slow
Soil pH	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral
Stratification due to sand	-	15 cm	67 cm	30 cm	46 cm	78 cm	20-25 cm	-	-	-

INSERT TABLE 15

Table 15. Actual soil productivity ratings, Index of potentiality (PI) and coefficient of Improvement (CI)

Parameter	**Series 1**	**Series 2**	**Series 3**	**Series 4**	**Series 5**	**Series 6**	**Series 7**	**Series 8**	**Series 9**	**Series 10**
Moisture (H)	100	70	100	80	100	100	100	100	100	100
Drainage (D)	80	80	80	80	90	80	80	80	80	80
Depth (P)	100	100	100	100	100	100	100	100	100	100
Base saturation (N)	100	100	100	100	100	100	100	100	100	100
Salinity (S)	100	100	100	100	100	100	100	100	100	100
Organic matter (O)	85	85	85	85	85	85	85	85	85	85
Clay CEC, $cmol_c kg^{-1}$(A)	85	85	85	85	85	85	85	85	85	85
Mineral reserve (M)	85	85	85	85	85	85	85	85	85	85

Actual productivity index (PI)	49	3.4	24	19	27	24	49	49	49	49
Rating class of PI	Good	Extremely poor	Average	Poor	Average	Average	Good	Good	Good	Good
Index of potentiality rating (IP) after improvement	85	8.5	42.5	25.5	42.5	42.5	85	85	85	85
IP rating class	Excellent	Poor	Good	Average	Good	Good	Excellent	Excellent	Excellent	Excellent
Coefficient of Improvement (CI)	**1.73**	**2.5**	**1.77**	**1.34**	**1.57**	**1.77**	**1.73**	**1.73**	**1.73**	**1.73**
Associated correctable limitations	D-O-A	H-O-A	D-O-A	H-D-O-A	O-A-D	D-O-A	D-O-A	D-O-A	D-O-A	D-O-A
Limitations un-correctable at farmer's level	M	T-M	T-M	T-M	T-M	T-M	M	M	M	M

Note: H=period of soil moisture between field capacity and wilting point in a year; D= flooding and drainage condition; P= effective depth of profile; T= texture and structure of soil; N= base saturation as an index of nutrient access; S= salinity hazard, O= soil organic matter; A= nature of clays and their CEC; M= mineral reserve

10.7.8 Crop Growth Models for Land Evaluation

The FAO framework is basically a classification system working with classified land data, inferring land qualities, and resulting in suitability classes. Initially this made sense as data was collected over map units. But with the advent of computer and multi-temporal/continuous sampling methods (remote sensing), it is possible to collect large quantities of data in space and time. This permits us to model the response of the land to various land uses, thus fulfilling the fundamental purpose of land evaluation i.e., assessment of land performance when land is used for specified purposes.

Crop growth modeling is a procedure through which yield can be simulated and used for land evaluation. The obvious advantage of this method is its ability to provide probabilistic estimates of yield and to include evaluation of spatial and temporal variations. Crop growth models can be empirical or mechanistic. Empirical models are developed by regressing a sample of yield with sample of input variable(s). Commonly, simple linear, non-linear or multivariate analysis are used to fit historical yield data to climate variables like mean temperature or precipitation. They are useful to predict yield potentials based on climate. However, they cannot be used directly for land evaluation. They do not account for dynamic changes of state variables. Moreover, the regression coefficients need to be calibrated when these models are applied to new circumstances.

Mechanistic or process oriented models are mathematical simulation of physiological, chemical and physical processes which govern crop growth. There is an unlimited potential to expand a simulation model based land evaluation system from the traditional biophysical modelling (Varcoe, 1990).

A major use of modeling for land evaluation is to predict yields (either average yields or time sequence). The value of the land is directly reflected by its productivity. The modeled yield, along with a price for the product, gives the gross return. Since yields vary with management level (e.g., type and level of inputs, timeliness of operations), modeling yield requires a careful specification of the input levels of farming systems.

Currently, models are used at three distinct levels in land evaluation

- As a scientific tool for the investigation of processes
- As a predictor of yield, and
- As a standalone evaluation or classification system

Modeling can also be used to predict some land qualities that are important components of yield, e.g. moisture supply, nutrient supply, radiation balance, as well as land qualities important for the land use but not directly affecting yield, e.g. trafficability and workability.

Advantages of crop growth models in agricultural land evaluation

(i) Simulation of yield provides a quantifiable method of classifying land
(ii) A large number of variables and complex interactions can be analyzed.
(iii) It provides a single, accessible, organized and standardized body of reference.
(iv) Simulation of result is a rapid and cheap method of investigation, particularly when time-frames or money do not permit data collection.
(v) The modelling process identifies particularly important inputs to each modeled system.
(vi) Simulation is often claimed to be scale-neutral in concept.
(vii) Simulation is useful for extrapolating experimental results to other sites where climate and soil conditions may differ.
(viii) Production assessments can be made for crops not previously grown in a region or to compare a range of crops.
(ix) Models can be continuously updated and modified.
(x) Models can be extended to incorporate economic and /or social constraints.
(xi) Estimation of the production levels can be used for valuation and taxation purposes

Disadvantages of crop growth models in agricultural land evaluation

(i) Even in mechanistic models many relationships are empirical.
(ii) There may be a tendency to accept simulated results without adequate validation.
(iii) Many models are very complex (at least initially) and may require detailed data.
(iv) Access to data is becoming increasingly difficult/costly.
(v) There are seldom comprehensive records of the required data at region or district level, particularly in less developed countries
(vi) Certain degree of expertise is needed to use simulation models.

Some commonly used crop simulation models in India

There are many dynamic simulation models to predict crop yield.

DSSAT: Decision Support System for Agro-technology Transfer (DSSAT) was developed by ICRISAT to estimate crop production, resource use and risks associated with different crop production practices. The software package contains crop simulation models, databases for weather, soils and crop and strategy evaluation programme integrated with a shell programme which is the main user interface. It contains the following families of models-

The CERES family for simulating wheat, maize, barley, sorghum and millets

The CROPGRO family models to simulate grain legumes-soybean, groundnut and dry bean and

ROOT crop models to simulate potato, cassava and aroids.

OTHER crops-Tomato, sunflower, sugarcane and pasture.

These crop simulation models simulate the effects of weather, soil, water, cultivar and N on crop growth and yield for well- drained soils.

INFOCROP: Developed by Aggarwal et al. (2004), it is a generic simulation model for annual crops in tropical environments. It uses weather (radiation, rainfall, temperature, wind speed, humidity,frost), soil (texture, pH, depth, fertility), variety (physiology, phenology and morphology), management (planting date, fertilization, irrigation and residue management) and pests (type, population and severity) as inputs. The outputs include, economic and biomass yield, crop duration, water stress, N stress, yield loss due to pests, soil C and N dynamics, and greenhouse gas emissions. Currently, it simulates chickpea, cotton groundnut, maize, mustard, pearl millet, pigeon pea, potato, rice, sorghum, soybean, sugarcane and wheat.

Aggarwal et al. (2001) adopted a systems approach combining simulation models and DSS for land use analysis and planning for sustainable food security in Haryana. Roetter et al. (2004) provided a detailed account of the Systems research Network (SysNet) for land use planning in tropical Asia with a focus on its main scientific – technical output: the development of the land use planning and analysis system (LUPAS) and its component models. These include crop simulation models, expert systems, GIS and multiple goal linear programming (MGLP) model for land evaluation and optimization.

Crop growth models are emerging as new tools for land evaluation to quantify production possibilities and constraints under different land use systems. There is no single land evaluation modelling approach. The choice of model affects the reliability and scope of application of the land evaluation. The models generally use data on land unit characteristics and land utilization attributes and generates estimates of production potentials. However, these models need to be calibrated and validated to local conditions before using. The paucity of accurate data to run simulation models is still a major obstacle in their widespread use as tools for quantitative land evaluation.

10.8 Conclusions

Among the different approaches of land evaluation, the land capability classification is applicable for grouping the lands into arable and non arable lands. While the irrigability classification attempts to group the lands into irrigable and non irrigable classes. Both these methods are qualitative and are based on inherent limitations of the lands. Categorization of prime and marginal lands is an approach which considers the limitations of the lands and has general use, whereas FCC deals with fertility aspects of the lands for better management. The Storie index and Requier's approach are multiplicative approaches used to arrive at productivity and potentiality of the lands. These methods though quantitative may not be useful for specific crops. FAO and Sys methods are used for land suitability for different crops. These methods are crop specific since they consider the crop requirements, land characteristics and land qualities. In present context, prime land classification assumes greater importance to conserve these lands for present and future needs of people. Second green revolution or Evergreen revolution will be a reality in near future. Therefore, integration of prime lands and land suitability for specific crops helps in conserving the land resources and also enhances the resource use efficiency. The application of models in land evaluation has limitations since they are mostly theoretical and need validation for wider applicability. Among the above approaches, the methods which consider land characteristics-qualities of a location and crop requirements are found to be better for crop planning and delineating efficient crop-zones. However, Riquier's approach needs to be refined under Indian situations to quantify the production levels of a given land unit. So, more systematic and location specific works are desired to authenticate the practical relevance with coefficient of improvement, so that profitable production could be enhanced considerably to ensure even more than double of the farmer's economic growth merely by improving the correctable limitations with a given land.

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