Agropedology 2005, 15 (1) 16-21

Productivity and irrigability classification of some basaltic soils in toposequence: A case study of Amensis sub-catchment at Hirna watershed in Western Hararghe, Ethiopia

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Abstract : The quantitative evaluation of the actual (productivity index) and potential (index of potentiality) productivity of soils in three distinct toposequences in Amensis sub-catchment of Hirna watershed was carried out following parametric method. The soils occurring in the mountainous steep sloppy landscape were grouped as extremely poor to poor whereas the soils of the valley/basin were grouped as good in their productivity index. The coefficient of improvement as being the ratio of potentiality index to the productivity index was very high in sloppy landscape of the first toposequence but low and almost identical in the lowlands. More improvement was desired in sloppy land provided that the limitations were correctable. Nature and severity of limitations indicated the extent and direction of improvement. Slope as a soil related parameter needs to be included in evaluating the soil productivity particularly in the Ethiopian highlands. Similarly, for irrigability classification, the capability index (Ci) was computed for each soil type. From topographic high to low, the severity of limitations were recorded as slope-texture-depth in case of steep sloppy land, slope-drainage-texture in foothill landscape, texture-slope-drainage in most of the soils in the topographic lows.

Additional Key words: *Basaltic soils, toposequence, productivity, irrigability, management option*

Introduction

Productivity is the existing capability of a soil to produce a certain amount of crop per unit area per unit time under existing situation, whereas potentiality is the soil productivity, which can be expected after all possible improvement is made. The soil resource data provide several parameters which may facilitate in predicting the behaviour and suitability of soils for growing the crops and forest or other plantation crops (FAO 1976; Sehgal 1996). Several systems of land evaluation have been proposed for land use planning in different regions. The Storie index is one among those methods, which has been widely used, but it is more generalized (Storie 1954). The soils developed even on the same parent material may be different in their response to management, if they suffer from the severity of different limitations. Relief position, textural class, taxonomic grouping, drainability, organic matter and nutrient status are some of the soil related features, which are very sensitive to the extent of productivity particularly of soils developed on basalt. Riquier *et al* (1970) did not consider the relief factor for evaluation of the soil productivity. Singh and Mishra (1996) used different methods to evaluate the soil productivity in the Gandak command of India. Sehgal (1981) suggested criteria of soil-site evaluation for forest plantation in Iraq. Banerjee (1973) observed that all growth attributes of *Acacia* spp. were reduced to about 50 per cent in shallow soils as compared to deep soils of the same texture. Sehgal (1981) reported a significant drop in growth components of *Eucalyptus* spp. as affected by soil depth, salinity and organic matter status.

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It is obvious that the potential crop yield is hardly possible without assured irrigation. In order to address this issue, it is suggested to evaluate the suitability of soil for effective utilization of irrigation water before adoption of actual practice, since execution of any irrigation programme is very expensive and unplanned execution results into disastrous consequences like salinity and alkalinity. In Ethiopia, where the land physiography is undulating bounded with series of hills and mountains, it is essential to classify the soils according to their suitability for irrigation. Special attention is paid on irrigability classification particularly due to three factors *i.e.* drainage, effect of irrigation water on soil salinity and alkalinity and the cost of land development (Sehgal 1996). Sys (1976) proposed a parametric method for evaluating the suitability of soil for irrigation. Singh and Mishra (1997) used this technique for irrigability classification of some sedentary and alluvial soils of India. The present investigation was aimed at parametric evaluation of the degree and extent of productivity and irrigability of soils of Hirna watershed of Ethiopia and some relevant management options thereof.

Materials and Methods

The details of the study area, climate and soils in different three toposequences were reported elsewhere (Heluf Gebrekidan and Mishra 2005). Relevant data were used to compute the productivity index (Requier *et al* 1970):

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

where, H is the soil moisture condition, D drainage, P effective depth, T texture and structure, N base saturation, S soluble salt concentration, O organic matter content, A mineral CEC and nature of clay minerals and M is the mineral reserves/weatherable minerals present in the soils. Each factor is rated on a scale from 0 to 100, the actual percentage being multiplied by each other. The resultant index of productivity in which factors are rated between 0 to 100, is set against a scale placing the soil in one of five productivity classes. The productivity index rating of 65-100 is excellent, 35-64 is good, 20-34 average, 8-19 poor and 0-7 is extremely poor to nil in productivity terms. The index of potentiality is an expression of potential productivity after soil management on the basis of evaluation report of the actual productivity index. Potentiality index was calculated keeping in mind that the improvement has been made and the soil qualities have been improved. However, there are certain soil parameters which cannot be improved just by applying the improvement measures and so there would be no change in their rating even after improvement. The coefficient of improvement of the soil is expressed by a ratio of potentiality index to the productivity index, which signifies the extent of improvement by application of all suitable management techniques. The coefficient of improvement is an effective tool to interpret in terms of yield increment of the crop within its maximum genetic (potential) yield.

The parametric approach for rating the soil related parameters followed the criteria suggested by Sys (1976) and the overall capability index (Ci) is computed.

Ci = A.B.C.D.E.F.G, where

A= rating for soil texture (taken as 100 for the best texture, say loam)

B= rating for soil depth

C= rating for $CaCO_3$ status

D= rating for gypsum status

E= rating for salinity and alkalinity status

F= rating for drainage condition, and

G= rating for topography/slope

(taken as fraction of one)

According to Sys (1976), Ci rating as 80 and more is assigned for very suitable to suitable, 60-80 for moderately suitable, 40-60 for marginally suitable, 20-40 for almost unsuitable and less than 20 is assigned for unsuitable soils for irrigation. Based on the classes identified for the soil irrigability grouping on parametric procedure, limitations associated with each class were recognized in order to suggest the economically viable management as well as conservation measures on sustainable basis to the land.

Results and Discussion

Productivity index

Following the criteria of rating for relevant soil parameters associated with soil productivity, the computed data are shown in table 1. A perusal of data indicates that the soils falling in the first toposequence and occurring in mountainous landform have very low values for productivity index and are assigned as extremely poor to average in actual productivity, though their relative values were differing. In this toposequence, the most limiting factors are texture, effective soil depth and moisture status.

In the second toposequence, the valley soils differ in their productivity mainly because of heavy texture. The soil depth is not a limiting factor. Based on the overall productivity index, these soils in their actual productivity qualify for good to excellent class. Only least effort may require to change the land to their better productivity status on sustainable basis. Careful scientific management could have improved the soil productivity to the excellent class.

The soils of the third toposequence indicate varying degree of productivity due to associated factors restricting the overall productivity index though all the four soils in the third toposequence qualify for good to excellent productivity classes.

A perusal of data further indicates that in all the soils, moisture either due to dry or moist condition would have adversely affected the productivity differently. Besides, the whole catchment showed differential nature of topography, wherein slope is contributing by itself to the productivity and this vital part has not been taken care of in the rating of productivity index. The availability of irrigation, ease of ploughing and other cultural practices get restricted due to slope. In Ethiopia, soils with slope gradient of even more than 80 per cent are under cultivation following conventional/traditional systems. Moreover, slope is the soil related feature and refers to the relief position, which contributes significantly to the soil formation. But Riquier *et al* (1970) did not consider its importance for productivity evaluation. However, in Ethiopian context, slope needs to be incorporated for more accurate results.

The overall productivity index was observed associated to some specific factor that could have declined the productivity. Obviously, approach was made to evaluate the extent of managements that could have improved the ratings for those factors under consideration. In doing so, the guidelines as suggested by Riquier *et al* (1970) were followed. For each factor causing the decline of productivity, possible management options were identified in order to

Table 1. Parametric evaluation of actual land productivity (PI)

Parameter	Toposequence 1			Toposequence 2			Toposequence 3				
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
Moisture,H	0.4	0.4	0.4	0.5	0.6	0.6	1.0	0.5	0.5	0.6	1.0
Drainage,D	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.8
Depth,P	0.5	0.2	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Texture,T	0.1	0.1	0.6	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9
B.S.,N	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
EC,S	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OM,O	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CEC,A	0.9	0.9	0.9	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
WM,M	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
PI	1.53	0.61	14.8	20.31	43.86	43.86	64.98	36.55	36.55	43.86	64.98
Class*	5	5	4	3	2	2	2	2	2	2	2

* 5, extremely poor; 4, poor; 3, average; 2, good; 1, excellent; P1-Pedon1

improve the rating for all such parameters. Since the soil depth is by and large supposed to be a non-correctable factor, virtually no management activity was suggested and the original rating for this factor was retained. The revised data over actual data after improvement were computed as shown in table 2. The computation of these data for each pedon indicated the soil characteristics already improved through management within the available farmer's resources.

The evaluation of the potential productivity through empirical approach over the actual productivity (productivity index) was made parametrically. A perusal of data indicates that necessary improvement was made possible to some of the correctable limitations. Obviously, there is an edge in the quantitative value of the initial status of productivity. The ratio of potentiality index to that of productivity index is called the coefficient of improvement. In fact, the coefficient of improvement refers to the productivity after improvement through the adopted management measures. Much scope of improvement was recorded in case of soils of the first toposequence and least improvement was possible to attain the maximum limits in case of other two toposequences. This approach seems to be very useful in evaluating the land qualities quantitatively for effective and scientific crop and livestock production on sustainable basis. However, we have experienced that not only the slope, but some other soil features are not coherent to the criteria given by Riquier *et al* (1970). The high clay soils hardly indicate poor drainage condition due likely to the presence of appreciable amount of organic matter, some zeolite mineral causing molecular filtering, presence of krotovinas and strong vertic characters like cracks and so. Obviously, there is need to validate the procedure in the Ethiopian context so that the improved technique may be utilized for effective soil management on sustainable basis.

Capability Index

A perusal of data (Table 3) indicates that three pedons in the first toposequence with very steep slope, shallow depth and gravelly texture were not at all suitable for irrigation, as Ci values vary between 11.34 and 19.44 only. However, the IVth pedon in the first toposequence was found to be marginally suitable, though the limitations were associated with slope, drainability and gravelly texture. The slope is the most severe limitation, which can not be corrected just by management. Soil and water conservation measures followed by short grass plantation may be the possible option instead of irrigation. However, in pedon 4,

Table 2. Parametric rating for managing the soils for improvement in terms of potential productivity and coefficient of improvement

Factor	Toposequence 1				Toposequence 2			Toposequence 3			
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
H	0.7	0.7	0.9	0.9	0.6	0.6	1.0	0.5	0.5	0.6	1.0
D	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9
P	0.5	0.2	0.8	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0
T	1.0	0.9	1.0	1.0	0.9	1.0	0.95	1.0	1.0	1.0	1.0
N	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
S	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
O	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
C	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
M	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
I.P.*	33.25	11.97	68.40	85.90	57.00	57.00	85.5	47.50	47.50	57.00	85.5
Add 10%	36.57	13.17	72.20	94.49	62.70	62.70	94.0	52.25	52.25	62.70	94.0
CI**	23.90	19.95	4.88	4.65	1.43	1.43	2.14	1.43	1.43	1.46	1.45

* Index of potentiality, ** Coefficient of improvement

Table 3. Parametric evaluation of soil irrigability class and the limitations involved with the soils of Amensis sub catchment

Factor	Toposequence 1				Toposequence 2			Toposequence 3			
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
Textural class, A	70	70	80	85	80	65	65	70	1.0	85	65
Soil depth, B	0.8	0.6	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$CaCO_3$ status, C	1.0	1.0	1.0	1.0	0.95	0.95	0.95	1.0	1.0	0.95	1.0
Gypsum status, D	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Salinity, E	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Drainage, F	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.8
Slope, G	0.3	0.3	0.3	0.7	0.7	0.8	0.9	0.5	0.7	0.8	0.9
Capability index, Ci	15.12	11.34	19.44	42.84	38.30	35.57	40.01	31.5	56.7	61.56	42.12
Limitation according to severity	Slope-- texture depth	Slope-- depth texture	Slope-- texture depth	Slope-- drainage texture	Slope- texture -drainage	Texture- slope- drainage	Texture- drainage- slope	Slope- texture- drainage	Slope- drainage	Slope- texture	Texture- drainage

drip irrigation method would be preferred under the participatory approach for watershed development in the catchment.

The second toposequence was virtually the topographic lows of the catchment. The Ci values for all three pedons in this toposequence appeared to be between 35.57 and 40.01, which indicate that these soils are almost unsuitable to marginally suitable. The limitations associated were mainly the slope, texture and the existing drainage conditions in their varying degrees. In this toposequence, soil depth is not a limitation in any way to restrict the suitability of soil for irrigation. Following the soil conservation through bench terrace, drip irrigation method would be the most preferred choice of irrigation in the two pedons occurring in upland and midland, but furrow irrigation in the lowland with tied ridges.

The pedons of the third toposequence are comparatively better for their irrigability. The capability index varied from 31.5 to 61.56. The first pedon in this toposequence is affected by slope, gravelly texture and drainage condition, second one by slope and drainage, third one by slope and clayey texture and fourth one by clayey texture and drainage. Pedons 1, 2 and 3 occur on slope more than 5% and need soil conservation measures preferably the bench terrace following the long term crop rotation and agro-forestry. Preferred choice of irrigation would be the drip irrigation, if feasible on participatory basis. However, the low land soils in pedon 4 of this toposequence may be irrigated by ridge and furrow methods.

Acknowledgements

The assistance during all field activities and sample preparation received from Tsegay Gossa, Girmaye Mekonen, Yitages Tameru and Berhanu Megistu of the field soil laboratory of AU is highly acknowledged. Grateful thanks are due to Mrs. Nigist Getahun for her keen interest in typing the manuscript.

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Received February 2004; Accepted January 2005