A MINIMUM DATA SET FOR ASSESSING SOIL QUALITY IN RANGELANDS

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Abstract
To identify the functioning of the soil-landscape system and its effects on plant growth for native rangeland, we developed a general approach for choosing the most representative indicators from large existing data sets, using data from mountainous rangeland in northern Iran. Multivariate analysis were used to determine the smallest set of chemical, physical, and biological indicators in the whole soil data set at each site. We defined this set as the minimum data set for evaluating soil quality. Considering time and budget limitations, two minimum data sets were selected. The efficacy of the chosen minimum data sets was evaluated for their capacity to assess rangeland capability by performing multiple regressions of each minimum data set against the plant growth characteristics: total yield, herbaceous plant production, and utilizable forage as iterative dependent variables. Variations in the plant response variables were best predicted by the variable, soil profile effective thickness. The next important indicators were: nutrient cycling index, total nitrogen percentage, slake test, grade of pedality; first layer thickness; and water retention at wilting point. Considering relationships between soil properties and plant growth indicates that plant variables in this rangeland are more sensitive to soil physical properties than to soil chemical properties.

Additional Keywords: indicator, site potential, productivity, index, principal components.

Introduction
Science-based indices of soil quality (SQIs) provide the necessary integration of information for land managers to make informed decisions about the complex issues involved in agroecosystem (or rangeland) management (Andrews and Carroll 2001). Considering basic soil functions i.e., provision of sufficient amounts of water, and nutrients, provision of resistance and resilience to physical degradation, and sustaining plant growth under an appropriate utilization, numerous soil analyses might be required to fully characterize the soil/plant system. However, analyses can be time consuming and costly and are sometimes open to different interpretations, leading to a decision dilemma. Using a minimum data set (MDS), reduces the need for determining a broad range of indicators to assess soil quality. To identify the smallest list of measurable soil properties that define the major processes functioning in soil, several MDSs have been proposed (Larson and Pierce 1991; Doran and Parkin 1996; Andrews and Carroll 2001). The above-mentioned MDSs often included many auto-correlated properties, were tedious and costly to collect, and sometimes were not specific to capability assessment of rangelands. With respect to landform using statistical analyses operating upon soil properties, we presented a method for the selection of suitable predictive indicators for the assessment of SQ for semi-arid rangeland in Iran.

Materials and Methods
Site description
Experimental data were collected from 234 land units (LU) in the Lar aquifer (35° 4′ 36″ and 35° 48′ 40″ N and 51° 32′ and 52° 4′ E) 78 km north of Tehran, Iran. The climate is semi-arid with a mild summer and very cold winter. The mean annual air temperature is about 7° C. The precipitation pattern is a Mediterranean regime with annual mean precipitation of 496 mm (Iranian Meteorological Organization 2001). Based on Soil Taxonomy (USDA-NRCS 1998), the area is occupied by Lithic and Typic Xerorthents, and Fluvaquents. To carry out this research three major vegetation types were identified: *Bromus tomentellus-Astragalus adscendens* (sub-area 1); *Bromus tomentellus-Onobrychis cornuta* (sub-area 2); and *Agropyron repense-Chaerophyllum macrospermum-Ferula galbaniflua* (sub-area 3). Geologically the sub-area 1 consisted of sandstone, and limestone. Sub-area 2 has predominantly thick-bedded green tuff; while in sub-area 3 thick-bedded limestone is prevalent.

Experimental design
The study was subdivided into Lus – the stratifying procedure was conducted using vegetation type maps and 1:50000 scale topography maps and Geographical Information System (GIS) technology. In a factorial completely randomized design considering the 3 vegetation types, 2 elevation classes (2500 to 2800m and 2800 to 3100 m), 4 general aspects (north, south, east, and west), and 5 slope classes (0-3%, 3-10%, 10-32%, 32-56%, >56%) a total of 120 possible LU ($3*2*4*5 = 120$) combinations. Taking into account 3 replicate sites for each LU 360 sample sites could be identified, however only 234 were found and sampled.

Soil sampling and laboratory analyses

Soil samples for determining chemical properties were collected from the top 10 cm of soil within each LU. The fine earth fractions (<2 mm) were retained for chemical analyses. Soil pH was determined using an electrode pH-meter for a saturated soil paste using deionised water (McLean 1982). The electrical conductivity (EC) was also measured in the saturated paste extract (Rhoades 1982a). Organic carbon was determined using the Walkley-Black method (Nelson and Sommers 1982). Total nitrogen % was measured using the Kjeldahl method (Bremner and Mulvaney 1982). To determine exchangeable potassium, the neutral 1 N ammonium acetate extraction method was used (Knudsen, Peterson et al. 1982). The Olsen method was used to determine extractable phosphate using a molybdate reaction for colorimetric detection (Olsen and Sommers 1982). Cation Exchange Capacity (CEC) was determined for soil samples from 40 LUs by replacement of exchangeable cations by ammonium acetate (Thomas 1982). These samples were collected from different LU randomly. Sodium Absorption Ratio (SAR) was calculated using analyses of saturated paste extracts for Na^{+} by flame photometry, and Ca^{2+} and Mg^{2+} by compleximetric titration using ethylene diamine- tetra acetic acid (EDTA) (U. S. Salinity Laboratory Staff 1954).

To determine soil physical characteristics, we dug a 1.50 by 0.70 m pit, to the depth of a hard layer but not deeper than 1.5 m, in the middle of each LU (N=234). To assess soil structure, ped abundance, size and shape and grade of pedality were evaluated and recorded. The soil profile effective thickness (SPET), was defined and measured as the equivalent soil depth consisting of <2mm particles (Rezaei 2003).The first layer thickness (FLT) was characterized as the soil that extends from the surface down to the top of the B horizon, including the A and AB horizons (or A and E horizons) (Benny and Stephens 1985). First layer effective thickness (FET) is the first layer thickness excluding coarse fragment content. Particle size analysis was by the hydrometer method for each layer (Rezaei 2003).Particle size was used to develop a predictor of soil water retention capacity (Rezaei 2003).

Sampling for yield measurement

We used the direct harvesting technique to measure total current year production (TY), production of herbaceous plant (HP), and utilizable forage (UF) (Bonham 1989). For yield production of the spinous plants only the current seasonal growth of each plant was estimated through measuring for a proportion of samples for the dominant species. Spinous plant production was subtracted from TY to calculate HP. Species were also sorted into the three categories, palatable, semi-palatable, and unpalatable species, to calculate the UF (Moghaddam 1998).

LFA data collection

The Landscape Function Analysis (LFA) method (Tongway and Hindley 1995) considers rangelands as landscape systems. Landscape organization index (LOI) is defined within the LFA procedure as the arrangement of zones that reflect run-on and run-off processes. Using the LFA method, we derived values for a LOI and three soil surface Landscape Function Analysis indices (LFI): Soil Stability index (SI), Infiltration index (Infil), and Nutrient Cycling index (NCI). The indices included relevant combinations of individual soil surface features, comprising soil cover, litter cover, cryptogam cover, crust brokenness, erosion features, deposited material, microtopography, slake test, and soil surface texture. The landscape organization data was collected for each LU along the line transects.

Indicator selection

We selected two MDSs with the following procedure using different combinations of indicators from which to select: MDS 1, included only soil chemical and physical properties; and MDS 2 started with the soil properties and landscape function analysis indices.

Step 1: We used Pearson correlation coefficients to determine the eligible dependent variables for inclusion in the second step. Those soil properties that did not show a strong relationship, a Pearson correlation coefficient <0.50, with range production (TY, HP, and UF), were eliminated from the data list.

Step 2: Principal Component Analysis (PCA) was employed as a data reduction tool to select the most appropriate indicators of site potential for the study area from the list of indicators generated in Step I. This step is similar to the procedures used by Andrews and Carroll (2001). Only the PCs with eigenvalues>1 were considered for identifying the MDS. Within each PC, indicators receiving weighted loading values within 10% of the highest weighted loading were selected for the MDSs. When more than one variable was retained within a PC, the correlations sum were examined to determine if any variable could be considered to be redundant. It was assumed that highly weighted variables were highly correlated, if their linear correlation (r) was >0.70.

Step 3: Multiple regression analysis, was considered to be an appropriate tool to assess that how well the selected minimum data sets represent range capability (site potential).

Results and Discussion

Step 1 (Eliminating unimportant variables)

The results of conducting step 1 are showed in Table 1. The variables, pH and SAR, were eliminated, as they were not well correlated with TY, HP, and UF. Presumably the range of values for those properties within the study area is insufficient to result in substantial differences in plant growth. The effects of other eliminated variables including clay, silt, and sand content, and structural porosity index have effectively been taken into account in the calculation of water retention capacity. Also, altitude and slope gradient have an influence on range production via several soil properties (Rezaei 2003).

Table 1. Variables remaining and deleted variables from the nominated list, and the correlation coefficient for relationships between these variables and plant response variables.

Variables			TY	HP	UF
Remaining variables	Landscape function indices	Stability index (SI)	0.57***	0.58***	0.53***
		Infiltration index (Infil)	0.70***	0.70***	0.60***
		Nutrient cycling index (NCI)	0.88***	0.87***	0.76***
		Landscape organization index (LOI)	0.69***	0.65***	0.57***
	Soil physical and chemical properties	EC	0.69***	0.73***	0.64***
		OC%	0.63***	0.63***	0.52***
		Total N%	0.68***	0.67***	0.54***
		Exchangeable Potassium (K)	0.58***	0.61***	0.51***
		Coarse fragment ratio (CFr)	-0.70***	-0.75***	-0.68***
		First layer thickness (FLT)	0.55***	0.60***	0.57***
		First layer effective thickness (FET)	0.67***	0.73***	0.69***
		Profile effective thickness (SPET)	0.70***	0.75***	0.69***
		Grade of pedality (GP)	0.68***	0.71***	0.66***
		Slake test (ST)	0.62***	0.66***	0.56***
		Water retention at field capacity (FC)	0.61***	0.65***	0.59***
		Water retention at wilting point (WP)	0.54***	0.57***	0.54***
		Plant available water (PAW)	0.62***	0.68***	0.60***
Deleted variables		Altitude	-0.27***	-0.32***	-0.25***
		Slope gradient	-0.36***	-0.42***	-0.33***
		SAR (sodium adsorption ratio)	-0.25***	-0.26***	-0.26***
		pH	-0.12	-0.10	-0.10
		Extractable Phosphorus (P)	0.50***	0.52***	0.38***
		Cation exchangeable capacity (CEC)	0.31*	0.29*	0.15
		C/N	-0.17*	-0.15*	-0.12
		Clay %	0.18**	0.15*	0.14*
		Silt %	0.18**	0.18**	0.11
		Sand %	-0.24***	-0.22***	-0.16*
		Structural porosity index (SPI)	0.33***	0.31***	0.29***
		Depth to water table (WT)	0.43***	0.46***	0.34***

Observations = 234; *, **, and *** indicate significance at 0.05, 0.01, and 0.001 levels of probability.
Where TY is total yield, HP is yield of herbaceous plant production, and UF is utilizable forage.

Step 2 (Selecting important variables)

We assumed that PC's receiving eigenvalues >1 best represent system attributes. Considering this criterion for the original soil data set, the first three PCs had, explaining more than 82% of variation in the potential MDS 1 indicators (Table 2). More than 77% of the variation among all original data sets including landscape function analysis indices was explained by the first three PCs in the PCA run for MDS 2 selection (Table 2). Table 2 shows that the first PC for MDS1 selection had five highly weighted variables within 10% of the highest factor loading. All five were also highly correlated using. The five indicators were FET, SPET, CFr, FC, and AW. This group of indicators implies that this first PC is mainly associated with soil water retention capacity. For inclusion in MDS1, SPET that has the highest factor loading and correlation sum (Table 3) was chosen to represent the first PC. For the second PC, EC, OC%, N%, and exK were within 10% of the highest factor loading. This group of four indicators relates mainly to soil chemical fertility. Due to the highest correlation sum (Table 3), N% was retained as the most important factor from this PC to be included in MDS1. In the third PC for MDS1 selection, FLT, ST, and GP were within 10% of the highest factor loading. The pattern and size of loading factors show that this PC is mainly concerned with soil stability. The ST was eliminated because it is with highly correlated GP. Therefore, FLT and GP were selected as representatives of the third PC to be included in MDS1. Overall, the indicators selected for MDS1, comprising only soil chemical and physical properties, were SPET, %N, GP, and FLT.

Table 2. Principal component loading matrix (factor loading) for both, only soil chemical and physical properties (MDS 1) and soil properties with landscape function indices derived by the LFA method (MDS 2).

Principal component loading matrix for soil physical and chemical properties (MDS 1)

Variables	**Principal components**		
	PC 1	**PC 2**	**PC 3**
EC	0.698	0.443	0.012
OC%	0.774	0.460	-0.240
Total N%	0.786	0.484	-0.240
K exchangeable	0.722	0.490	-0.192
First layer thickness (FLT)	0.684	-0.030	0.437
First layer effective thickness (FET)	0.848	-0.012	0.301
Profile effective thickness (SPET)	0.921	-0.276	-0.039
Coarse fragment ratio (CFr)	-0.916	0.271	0.035
Water retention capacity at FC (FC)	0.877	-0.375	-0.258
Water retention capacity at WP (WP)	0.795	-0.421	-0.246
Available Water capacity (AW)	0.888	-0.292	-0.248
Slake test (ST)	0.657	0.026	0.488
Grade of pedality (GP)	0.719	0.056	0.472
Eigenvalues	**8.241**	**1.439**	**1.086**
Proportion	0.634	0.111	0.084
Cumulative	0.634	0.745	0.828

Principal component loading matrix for soil properties accompanied by landscape function indices (MDS 2)

Variables	Principal components		
	PC 1	**PC 2**	PC 3
EC	0.713	0.268	**0.292**
OC%	0.773	0.165	**0.446**
Total N%	0.792	0.194	**0.461**
K exchangeable	0.721	0.183	**0.468**
First layer thickness (FLT)	0.676	-0.013	**-0.167**
First layer effective thickness (FET)	0.836	-0.048	**-0.101**
Profile effective thickness (SPET)	0.900	-0.322	**-0.112**
Coarse fragment ratio (CFr)	-0.894	0.323	**0.105**
Water retention capacity at FC (FC)	0.840	-0.497	**-0.030**
Water retention capacity at WP (WP)	0.760	-0.506	**-0.081**
Available water capacity (AW)	0.852	-0.443	**0.028**
Slake test	0.684	0.284	**-0.447**
Grade of pedality (GP)	0.750	0.278	**-0.378**
Stability index (SI)	0.543	0.429	**-0.466**
Infiltration index (Infil)	0.684	0.356	**-0.071**
Nutrient index (NCI)	0.859	0.276	**-0.028**
Landscape organization index (LOI)	0.734	0.118	**0.155**
Eigenvalues (Latent roots)	**10.09**	**1.638**	1.376
Proportion	0.594	0.096	**0.081**
Cumulative	**0.594**	**0.690**	**0.771**

Table 3. Correlation coefficients and correlation sums for highly weighted variables within the principal components (PCs) shown in Tables 2 with multiple high factor loadings .

Correlation coefficients and correlation sums for soil physical and chemical properties (MDS 1)

PC1 variables	**FET**	**SPET**	**CFr**	**FC**	**AW**
FET	1.00	0.76	-0.77	0.65	0.67
SPET	0.76	1.00	-0.99	0.81	0.92
CFr	-0.77	-0.99	1.00	-0.88	-0.91
FC	0.65	0.89	-0.88	1.00	0.95
AW	0.67	0.92	-0.91	0.95	1.00
Correlation sums	3.85	4.56	4.55	4.29	4.45
PC2 variables	**EC**	**OC**	**N**	**K**	
EC	1.00	0.60	0.67	0.70	
OC	0.60	1.00	0.96	0.74	
N %	0.67	0.96	1.00	0.76	
K	0.70	0.74	0.76	1.00	
Correlation sums	2.97	3.30	3.39	3.20	
PC3 variables	**FLT**	**ST**	**GP**		
FLT	1.00	0.42	0.5		
ST	0.42	1.00	0.77		
GP	0.50	0.77	1.00		
Correlation sums	**1.92**	**2.19**	**2.27**		

Correlation coefficients and correlation sums for soil properties accompanied by landscape function indices (MDS 2)

PC1 variables	**FET**	**SPET**	**CFr**	**FC**	**AW**	NCI
FET	1	0.76	-0.77	0.65	0.67	**0.67**
SPET	0.76	1	-0.99	0.81	0.92	**0.69**
CFr	-0.77	-0.99	1	-0.88	-0.91	**-0.68**
FC	0.65	0.89	-0.88	1	0.95	**0.6**
AW	0.67	0.92	-0.91	0.95	1	**0.61**
NCI	0.67	0.69	-0.68	0.6	0.61	**1**
Correlation sums	4.52	5.25	5.23	4.89	5.06	**4.25**
PC2 variables	**FC**	**WP**				
FC	1	0.96				
WP	0.96	1				
PC3variables	**ST**	**OC**	**N**	**K**	**SI**	
ST	1	0.44	0.44	0.37	0.65	
OC	0.44	1	0.96	0.74	0.32	
N %	0.44	0.96	1	0.76	0.34	
K	0.37	0.74	0.76	1	0.29	
SI	0.65	0.32	0.35	0.29	1	
Correlation sums	**2.9**	**3.46**	**3.51**	**3.16**	**2.6**	

Where FET is first layer effective thickness, SPET is soil profile effective thickness, CFr is coarse fragment ratio, FC is water retention capacity at field capacity, AW is available water capacity, EC electrical conductivity, OC is organic carbon %, K is exchangeable potassium, ST is slake test, FLT is first layer thickness, GP is grade of pedality, NCI is nutrient cycling index, WP is water retention capacity at wilting point, and SI is stability index.

The first PC for MDS2, incorporating both soil and landscape variables, was mainly associated with soil water storage and nutrient pool factors (Table 2). The variables relating to soil water capacity (CFr, SPET, FET, FC, and AW) and NCI are within 10% of the highest loading factor, which is for SPET. The highly weighted variables related to water holding capacity were also all highly correlated with SPET (Table 3) and thus were considered as redundant. Of this group, SPET was selected for the MDS 2 as the representative of the entire water holding variables group based on its having the highest correlation sum and the highest loading factor. The NCI was retained as the representative of the nutrient pool. The proximity of loading factor sizes for SPET and NCI confirms the statements of Power (1981) and Benny and Stephens (1985) that SPET is an important parameter in determining soil functions relating to storage of both plant available water and nutrients. From the second PC, FC and WP received the highest loading factors, which were highly correlated (Table 3). The WP has been selected as the representative of the second PC to be included in MDS2. In the third PC, two groups of variables received high factor loadings: a nutrient availability group and a soil stability group. The nutrient group consisted of OC%, N%, and exK. The stability variables were of ST and SI. Of the nutrient variables, N% has the highest correlation sum (Table 3). However, the absolute value of the loading factor for exchangeable K is higher than for N%. In addition, the correlation between N% and NCI (an indicator selected under PC 1) is much higher (r =0.69) than correlation between exchangeable K and NCI, making exK the less redundant choice for indicator of the nutrient availability in third PC. The NCI, which is an integrative index, are to some extent correlated with the concentrations of OC and total N % (Tongway 1995). Therefore, having NCI together with exK in the data set instead of N% or OC% can identify aspects of soil fertility other than those represented by OC% and N%. However in the absence of data for exK, the total N data can be recommended as the best surrogate for exK to predict plant growth characteristics. For the stability indicators, the absolute factor loading for SI was higher than for ST. However, due to a higher correlation sum for ST and closer relationships between ST and plant production variables compared with SI, ST was chosen as the representative of stability function for MDS2.

Finally from all the nominated indicators in Table 2 for MDS 2, five indicators, SPET, NCI, K, WP, and ST were retained. The PCA results and subsequent MDS selection suggest that soil basic functions (i.e., maintaining productivity, regulating and partitioning of water and solute flow, storing and cycling nutrients, and soil stability) are important for soil quality assessment and site potential assessment of rangeland. The selected indicators of these soil functions are summarized for both MDSs in Table 4.

Table 4. Indicating proposed soil property minimum data sets with and without inclusion of landscape function analysis indices.

Soil functions	Minimum data set for soil physical and chemical properties (MDS 1)	Soil properties accompanied by landscape function indices (MDS 2)
Fertility	Total nitrogen % (N%)	Exchangeable potassium (K)
		Nutrient cycling index (NCI) (from LFA)
Water retention capacity	First layer thickness (FLT)	Water retention capacity at wilting point (WP)
	Soil profile effective thickness (SPET) Available water capacity (AW) #	Soil profile effective thickness (SPET) Available water capacity (AW) #
Stability	Grade of pedality (GP)	Slake test (ST)

Substitution for SPET in areas with less coarse fragment.

Step 3 (Testing the MDS through multiple regression analysis)

The multiple regression functions for all plant growth characteristics i.e., TY, HP, and UF, involved all 4 proposed variables within the MDS 1. The most predictive model for HP explained more than 72% of the variation. The model for TY was slightly less predictive (coefficient of determination (R^2) = 0.67), which is reasonable, because production of non-herbaceous plants e.g., *Onobrychis cornuta* and *Astragalus adscendens* with long roots partly depend on water and nutrients within a soil column larger than the 150 cm depth investigated in this research. The major factor associated with variation in all plant response variables was SPET, which has a close relationship to the water holding capacity. After SPET, total N % explained most of remaining variation for all response variables. In contrast to TY (R^2 = 0.67) and HP (R^2 = 0.72), the model for UF is less predictive, (R^2 = 0.59). The major reason for this difference may be that the utility of forage is strongly dependent on plant palatability, which in turn is dependent on plant species, i.e., plant genus, plant inherent palatability, rather than only on site productivity. This statement highlights the observation that plant species composition is an important factor that should be taken into consideration when considering soil productivity and site potential within range suitability assessment programs.

The stepwise multiple regression functions for predicting TY and HP using MDS 2 involved all 4 proposed variables within the MDS 2. However for HP only three variables, i.e., NCI, SPET, and ST, were included in the model. The predictions have been plotted as predicted versus measured values for TY, HP, and UF. The most predictive model was that for yield production of HP, which explained 83% of variation followed by the model for TY, which explained 80% of total yield variation. The least predictive model was for UF which explaining only 64 % of variation. The major factors associated with variation in all response variables were NCI followed by SPET.

Conclusion

The MDSs were utilized for soil quality assessment with respect to the management goals of soil productivity and stability. Depending on the required accuracy, time restrictions, and budget either MDS1 or MDS2 could be employed for rangeland capability assessment. Since MDS 2, by taking into accounts landscape function indices, provides a better prediction of range production; if there are no limitations on budget and time it is better to use MDS 2 components to predict soil productivity and stability in rangelands. The MDS 2 components describe most of the soil basic functions including: (1) the ability to hold, accept, and release water to plants (2) maintain productivity (3) and to respond to management and resist degradation. Similarly, comparison of the MDSs, with and without landscape function analysis indices, showed that the proposed MDSs, especially MDS 2, are consistent with the conceptual basis of LFA includes (1) the soils ability to absorb and store rainfall, (2) the soils ability to store and cycle nutrient elements, (3) the soils resistance to erosion, (4) the soils capacity to provide an appropriate habitat for seed germination and plant growth (Tongway and Murphy 1999). The NCI as an integrative indicator explains most of the variation in soil productivity for rangelands better than does any other single variable.

Acknowledgements

Research was funded by Forest and Range Organization of I. R. of Iran. Authors wish to thank Dr. H. Mirzaie Nodoushan for his assistance in statistical analyses.

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