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Assessing rangeland capability in Iran using landscape function indices based on soil surface attributes

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Abstract

To identify the functioning of the soil-landscape system and its effects on plant growth for native rangeland the relationships between soil properties and landscape function analysis (LFA) indices and between plant growth characteristics and LFA indices were investigated. The results interpreted based on statistical analysis and expert knowledge. This research was carried out for a semi-arid rangeland in the Lar aquifer in Iran. Land stratification allowed the study area to be subdivided into Land Units, according to specified criteria including landform attributes (slope, aspect, and altitude), and vegetation type. A factorial model on the basis of a completely randomized design was used to analyse the data collected from 236 land units. The landscape function indices including nutrient cycling index, infiltration index, stability index, and landscape organization index were derived by various integrations of soil surface attributes. Landscape attributes differed from one another in their effects on the different landscape function indices. Increasing slope gradient significantly reduced all landscape function indices as well as soil organic carbon and total nitrogen percentages. Slope class exhibited highly significant interaction effects with vegetation type factors for stability, nutrient cycling, and landscape organization indices. Aspect did not significantly affect stability, infiltration, and landscape organization indices, but significantly affected the nutrient cycling index. The Duncan test indicated that north aspect (shady side) had the highest mean

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value (28.42) and south aspect the lowest mean value (25.57) for nutrient cycling index. These results are consistent with the effects of aspect on total soil nitrogen and soil organic carbon percentage for which the north aspect had the highest values. The values declined in the sequence east, west, and south aspects, respectively. This research indicates that the nature of native rangeland plant communities and their measures of production are closely related to nutrient cycling index.

Keywords: Landscape function analysis; Landscape attributes; Soil properties; Rangelands

1. Introduction

The most important and basic bio-physical resource of rangeland is the soil. The history of soil science shows that some soil surface functions and soil properties are strongly related to soil productivity and stability. Investigation of relationships between plant cover, runoff, and sediment transport by Greene et al. (1994) found a significant negative relationship between runoff rate and plant cover. They showed that soil productive potential may be changed without the occurrence of significant actual soil loss. In this situation the vegetation attributes should be evaluated in relation to the criteria for site conservation. Those soil cover situations that meet the criteria for protection of the land would be assigned as site conservation ratings.

In the 1990s some researchers started to identify and use soil properties in range condition assessment and range monitoring (Tongway and Smith, 1989; Ludwig and Tongway, 1993). In 1995 Tongway and Hindley published a manual for assessing soil surface condition of rangelands in Australia. He identified some diagnostic factors of the soil surface based on indicators of surface hydrology. Developing Tongway and Hindley's method of soil condition assessment at the hillslope scale, Ludwig and Tongway (1997) adopted a new framework entitled "Trigger-Transfer-Reserve-Pulse". This framework enabled the simply observed soil surface indicators to assess the landscape function at the hillslope scale. The framework enables the determination of threshold amounts of available resources. The most important of which are water and nutrient supply. Through analysis of landscape function, some ecologists can judge the landscape's capability based on how it works as a biogeochemical system, ranging from being fully functional to entirely dysfunctional. This respectively characterizes systems as highly conserving to leaky of vital resources, or from completely robust to totally vulnerable (Ludwig and Tongway, 1997; Herrick and Wander, 1998).

The indices derived in the methodology of landscape function analysis (LFA) using soil surface attributes that can generally be used in range capability assessment and especially in rangeland monitoring and management programs are:

1. Stability (resistance to erosion)
2. Infiltration (capacity for rain and run-on water to infiltrate)
3. Nutrient cycling (organic matter decomposition and cycling)

4. Landscape organization, reflecting the overall resource use economy of a hillslope.

Soil surface cover in the LFA approach includes living and dead vegetative material and non-transportable material such as stones and rocks. This is in agreement with the approach taken in the universal soil loss equation (Rosewell, 1997). To determine the soil surface condition in LFA, Tongway and Hindley (2004) used different combinations of individual soil indicators. The objective of using these indicators is to assess the degree to which soil surface cover will intercept raindrops and protect the soil from rainsplash erosion. Soil with more protection has a lower potential for future erosion, even if the protection is in the form of a layer of stones caused by previous erosion.

In range capability assessment, parameters such as rangeland production and rangeland stability are the consequence of the holistic system function comprising soil, plant, and environmental factors. Landscape function indices are a potentially useful short cut to laborious, expensive, and time-consuming direct measurement of those vegetation attributes that can be adversely affected by anthropogenic impacts. A necessary first step in applying indices developed elsewhere is to test their validity in new environment. Therefore, to identify the reliability and effectiveness of landscape function indices using soil surface attributes in estimation of site potential and monitoring purpose in the semi-arid rangelands of Iran we carried out present experiment in an alpine rangeland of Iran.

2. Materials and methods

2.1. Site description

The data were collected from three vegetation types within the Lar aquifer, between 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 mean monthly temperatures ranging from −6.5 °C in January to 18.4 °C in July (Iranian Meteorological Organization, 2001). The annual mean precipitation is 496 mm, most of which falls during winter and spring seasons (November–May). Altitude ranges between 2500 m (Lar Dam) and 3950 m. The general landscape of the study area is mostly steeply mountainous terrain dissected by valleys (Fig. 1). Based on US soil taxonomy classification, the study area is classified into different great groups of Lithic and Typic Xerorthents, Typic Haploxerepts, Haploxeralfs, and Fluvaquents (USDA-NRCS, 1998).

2.2. Vegetation

In the study area three major plant community types (herb, shrub-grass, and grass) consisting of 15 different vegetation types were identified; three of which: *Bromus tomentellus-Astragalus adscendens* (Type I); *Bromus tomentellus-Onobrychis cornuta* (Type II); and *Agropyron repense-Chaerophyllum macrospermum-Ferula*

Fig. 1. A general landscape of the study area.

galbaniflua (Type III) were chosen for this research. Each vegetation type has different underlying geology. Historically the Lar watershed has been exploited as a summer rangeland, which mainly is grazed by sheep and some goats in an extensive-grazing system. The grazing pressure in the three vegetation types is almost the same, although the type I relatively managed better than the other types. The type I consists of shale, sandstone, and limestone with subordinate sandstone. Type II has predominantly thick-bedded green tuff, tuffaceous shale, marl, and conglomerate. However, type III thick-bedded limestone is prevalent (Vahdati Daneshmand, 1997).

2.3. Soil sampling and laboratory analyses

The first step of the project was land stratification into land unit tracts (LUT), according to criteria including landform attributes (slope, aspect, altitude), and vegetation type. LUT is defined as "an area of land where the attribute values are sufficiently uniform and distinct from those of neighboring areas to justify its delineation in a map or image" (Gunn and Aldrick, 1988). The stratifying procedure produced thematic map layers from vegetation type maps, 1:50 000 scale topography maps, and a digital elevation model. In a factorial completely randomized design considering the three vegetation types, two elevation classes (2500–2800 m and 2800–3100 m), four general aspects of (north, south, east, and west), and five slope classes (0–3%, 3–10%, 10–32%, 32–56% and 56–100%) a total of 120 different LUs ($3*2*4*5 = 120$) could be created. Taking into account three replicate sites for each LUT "located in quite different parts of the study area" in order to produce a measure of diversity of soil properties within each LUT, 360 sample sites could be identified; however, only 236 were found and sampled. For all of the soil and plant response variables a factorial model on the basis of a completely randomized design was used for data analysis.

Samples were taken from a total of 236 transects within stratified land units. At least three transects were located in each LUT. Each transect was oriented parallel to the general slope in the middle of each land unit. Soil samples for chemical analyses were collected from the top 10 cm of soil within four plots of 0.5 m^2, which were located at 6, 12, 18, and 24 m along the 30 m transect. The samples were air dried at room temperature, lightly crushed with a pestle in a ceramic mortar and passed through a 2 mm sieve. The fine fraction (<2 mm) was weighed and retained for chemical analysis. Soil pH was determined using a glass electrode-calomel ($Hg–Hg_2Cl$) electrode pH-meter for a soil paste saturated with the distilled water (McLean, 1982) and electrical conductivity was measured for the saturation extract (Rhoades, 1982a). Organic carbon was determined using the potassium dichoromate oxidation (Walkley-Black) method (Nelson and Sommers, 1982). Total nitrogen was measured using the Kjeldahl method (Bremner and Mulvaney, 1982), exchangeable potassium by neutral 1 N ammonium acetate extraction (Knudsen et al., 1982). The Olson method was used to determine extractable phosphate (Olsen and Sommers, 1982). To determine soil physical characteristics, a pit was dug in the middle of each transect to bedrock to a limit of 150 cm. Profile description followed the procedure in the Australian Soil and Land Survey Field Handbook (Gunn and Aldrick, 1988).

To assess soil structure, ped abundance, size and shape and grade of pedality were evaluated and recorded. The first layer thickness 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 is the first layer thickness excluding coarse fragment content. Coarse fragment density, required to determine bulk density in gravely soil and to convert the mass data into volumetric data, was determined by water immersion using coarse fragments from representative samples collected from each geological subarea (Rezaei, 2003). Particle size analysis was by the hydrometer method (Klute, 1982) for each layer. The hydrometer method of particle size analysis was more reliable than the pipette method for these soils

2.4. Plant sampling and measurement

We used the current year's production of above-ground biomass (yield) as an indicator of potential plant growth for the soil-landscape system. The above-ground biomass was determined by cutting grasses and forbs to ground level in four plots of 0.5 m^2 along each 30 m transect. For yield production of the spiny plants only the current seasonal growth of each plant was estimated through measuring for a proportion of samples for the dominant species, such as *A. adscendens* and *O. cornuta*. This was calibrated by a double sampling method (Bonham, 1989). The estimated spiny plant production was subtracted from total dry matter yield to calculate herbaceous plant production. The harvesting time for the yield production was chosen on the basis of flowering time for the dominant species in each vegetation type, which strongly depends on the altitude and aspect, and the microclimate in the study area. Utilizable forage was determined by estimating palatability class. So the species were sorted into the three categories comprising palatable (class I), semi-palatable (class II), and unpalatable species (class III).

2.5. LFA data collection and analysis

The LFA method (Tongway and Hindley, 1995, 2004), was employed to derive values for the slake test, landscape organization index (LOI), and three soil surface indices namely: soil stability index, infiltration index, and nutrient cycling index (NCI) from different combinations of the individual soil surface features comprising soil cover, litter cover, cryptogam cover, crust brokenness, erosion features, deposited material, microtopography, slake test, and soil surface texture. In the LFA method the acquisition of ‘‘landscape organization'' data was conducted for each LUT along a line transect. Landscape organization that relates to vegetation cover is defined as the arrangement of zones that reflect run-on and runoff processes. Analysis of variance was conducted on the data to examine the importance of stratifying factors (aspect, slope, elevation, and vegetation type) on response variables, which are the LFA indices.

3. Results and discussion

For those LFA indices for which the main effects of stratifying factors were significant at $p<0.05$, the mean values of LFA indices for stratifying factors were classified. The Duncan multiple range procedure was used for the classification (Table 1). The mean value for those factors for which interaction effects were significant at $p<0.05$ are shown in Table 2.

Soil surface indicators for rangelands that are mainly dynamic in nature were directly affected by landscape attributes in addition to the indirect influences of landscape attributes via plant characteristics, e.g. plant species, plant growth form, and density. These effects may alter with historical management.

3.1. Effect of stratifying factors

On the basis of analyses of variance (ANOVA), aspect did not significantly affect stability index, infiltration index, and LOI, but significantly affected NCI. The Duncan test indicated that north aspect (shady side) had the highest mean value (28.42) and south aspect the lowest mean value (25.57) for NCI. The mean values for NCI for eastern aspect and western aspect were not significantly different. These results are consistent with the effects of aspect on total nitrogen and organic carbon percentage for which the north aspect had the highest values of total nitrogen and organic carbon; values declined in the sequence east, west, and south aspects, respectively (Fig. 2). Thus the shady side can accumulate more organic carbon and nitrogen than other aspects, especially the southern aspect (sunny side in north

Table 1
Classification of the means of the LFA indices for stratifying factors (across classes) using the Duncan test at $^{\#}p<0.05$

Factors	Classes	Stability index	Infiltration index	Nutrient cycling index	Landscape organization index
Aspect	East	63.00±0.69	33.80±0.61	26.79±0.72ab	0.42±0.02
	West	63.07±0.68	33.53±0.61	26.92±0.71ab	0.42±0.02
	South	62.17±0.73	33.73±0.66	25.57±0.89b	0.38±0.02
	North	62.38±0.73	35.41±0.82	28.42±0.97a	0.45±0.02
Elevation	2500–2800 m	62.95±0.46	34.53±0.43	27.60±0.56	0.43±0.01
	2800–3100 m	62.17±0.55	33.36±0.54	25.69±0.57	0.39±0.02
Slope	0–3%	67.61±0.85a	38.48±1.37a	32.59±2.16a	0.50±0.04a
	3–10%	64.96±0.67b	35.96±0.92b	29.92±1.14b	0.48±0.02ab
	10–32%62	62.22±0.66c	34.72±0.57bc	27.22±0.66c	0.44±0.02b
	32–56%	62.47±0.58c	33.20±0.53dc	26.75±0.65c	0.42±0.02b
	>56%	60.33±0.86c	31.70±0.76d	22.72±0.72d	0.32±0.02c
Vegetation type	*Br to-As sp* (1)	63.08±0.53b	33.73±0.51b	25.49±0.62b	0.35±0.01c
	Br to-On co (2)	60.78±0.52c	32.53±0.43b	25.59±0.43b	0.42±0.01b
	Ag re-Ch mu-Fe sp (3)	65.68±0.76a	37.91±0.81a	32.27±1.13a	0.52±0.02a

Data represented by mean±SE (standard error). Means with the same lower case letters are not significantly differed ($p<0.05$).

hemisphere) as found by McIntosh et al. (2000) in a study in a mountainous area in New Zealand. This difference may be due to differences in the amount and quality of plant residue inputs and at the same time to differences in the slower decomposition rate of organic matter in shady sides, which because of the cooler microclimate and higher soil moisture is less than for sunny aspects. These explanations also apply to the effect of being on the shady side on NCI and organic carbon.

Only NCI had significant interaction effect involving aspect, which was for aspect with vegetation types II and III (Table 2). However, the north aspect still had the highest mean values for NCI for the three vegetation types (subareas). The highest value for NCI is 37.38 for the north aspect of vegetation types 3 (*Agre-Chma-Fega*), which is followed by 26.94 and 26.35 for north aspects in vegetation types 2 (*Brto-Onco*) and vegetation type 1(*Brto-Asad*), respectively. The lowest mean values are for the south aspect, which decrease in order of vegetation type 3 > vegetation type 1 > vegetation type 2.

The results of the ANOVA provide evidence that vegetation type is related to the NCI via biomass allocation, growth form and/or life pattern of the vegetation. Vegetation type had highly significant influences on infiltration index, NCI, and LOI (Table 1). Duncan test results for the differences between means shows no significant difference between means for NCI for vegetation type 1 (*Brto-Asad*) and vegetation type 2 (*Brto-Onco*), which have the same growth form (*grass-cushion plant*). Also for

Table 2
Classification of the means of the LFA indices for interaction effects across classes within each factor for (vegetation type∗slope) and (vegetation type∗aspect)[a]

Factors	Factors		Vegetation type		
	Response variables	Factor classes	Type I	Type II	Type III
Slope class	Stability	0–3%	63.45 ab	No data	68.25 a
		3–10%	67.23 a	62.64 a	65.44 a
		10–32%	64.74 a	58.77 b	67.36 a
		32–56%	63.29 ab	61.06 ab	63.80 a
		>56%	58.89 b	62.25 ab	56.06 b
	Infiltration	0–3%	32.25 b	No data	39.44 ns
		3–10%	38.00 a	33.12 ns	37.34 ns
		10–32%	35.07 ab	33.29 ns	38.35 ns
		32–56%	32.54 b	32.27 ns	37.03 ns
		>56%	31.60 b	31.38 ns	35.03 ns
	Nutrient index	0–3%	23.05 b	No data	34.05 a
		3–10%	31.58 a	27.03 a	31.78 a
		10–32%	26.56 b	25.52 ab	33.96 a
		32–56%	25.24 b	26.22 ab	31.72 a
		>56%	21.68 b	23.80 b	22.1 b
	Landscape organization index	0–3%	0.19 c	No data	0.55 a
		3–10%	0.45 a	0.48 a	0.49 a
		10–32%	0.38 ab	0.43 ab	0.56 a
		32–56%	0.35 ab	0.43 ab	0.55 a
		>56%	0.28 bc	0.36 b	0.22 b
Aspect	Nutrient index	East	25.22 a	25.33 ab	32.49 ab
		West	25.27 a	25.19 ab	33.43 ab
		South	25.25 a	24.01 b	28.08 b
		North	26.35 a	26.94 a	37.38 a

[a]Lower case letters indicate classes where significant differences ($p<0.05$) exist among the factor classes in LFA indices and ns is used to indicate non significant effects. Means with the same letter are not significantly different from each other.

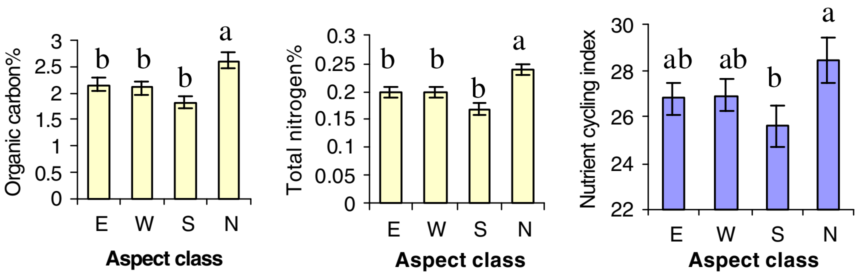

Fig. 2. Mean values of organic carbon, nitrogen, and NCI for different aspect classes. Vertical lines on bars show the standard error. Small letters indicate different grouping where significant differences ($p<0.05$) exist among different classes of each stratifying factors. Means with the same letter are not significantly different from each other.

all LFA indices vegetation type 3 had the highest mean value followed by vegetation type 1 and 2. There were no significant differences between means for infiltration index and NCI for vegetation types 1 and 2. Values for infiltration index and NCI for vegetation type 1 and 2 are almost the same. This similar response of vegetation types 1 and 2 may be related to the similarity of plant growth form and plant composition in these subareas.

Increasing slope gradient significantly reduced all landscape function indices as well as soil organic carbon and total nitrogen percentages; however, there were not significant differences between values for slope classes of 10–32% and 32–56% (Table 1). The Duncan test indicated that the highest mean value is for slope class 0–3% and the lowest value is for slope class >56% for all LFA indices. However, slope class identified highly significant interaction effects with vegetation type for soil stability index, NCI, and LOI. Although, the study area is relatively well managed, in some part of the area especially low slope adjacent to the water points there are some over grazed land. Therefore, one may conclude that these interactions mostly relate to mismanagement by over grazing rather than to inherent differences for the different vegetation types (Table 2).

Considering the influence of elevation, the means of the landscape function indices for the second elevation class (2800–3100 m) were less than for the first elevation class (2500–2800 m), but the differences were not statistically significant (Table 2). Significant interaction affects between vegetation type and slope class for all LFA indices except for infiltration index. The mean value of LOI for slope class of 0–3% is less than mean values of LOI for higher slope classes and even including very high slopes (>56%), which is intuitively inconsistent; however, this lowest slope class (0–3%) is located along the major water point (river), which is severely overgrazed by livestock; therefore, the state of this land reflects the mismanagement of rangeland, and not the effect of slope gradient on the land and vegetation. The mean values of LFA indices for other slope classes decreased with increasing slope gradient for vegetation types 1 and 2 (Table 2). However, for Vegetation type 3, which historically is a well-managed land, there were no significant differences between mean values of all LFA indices for slope classes of 0–3%, 3–10%, 10–32%, and 32–56%. However, slope class >56% had a significant effect on all LFA indices.

3.2. Bivariate relationships

An investigation of the relationships between LFA indices and plant characteristics, landscape attributes, and properties of the soil top layer using Pearson correlation and simple regression indicated that the strongest relationship with these variables is for NCI, followed by LOI, and stability index. For brevity, these correlation and regression analyses are not presented here, but are available upon request from the senior author. These three indices had negative significant correlations with the amount of coarse fragments bigger than 60 mm, coarse fragment ratio, bulk density, slope gradient, coarse material less than <60 mm, and altitude. These indices are highly positively correlated with plant response variables especially total yield, and also with first layer effective thickness, and soil nutrient elements including total nitrogen, organic carbon, exchangeable potassium, and extractable phosphorous.

It was expected that infiltration index would be positively related to the amount of coarse material which is less than 60 mm in size, but the opposite relationship ($r = -0.37$) occurred. This unexpected result is due to the infiltration index being related to both soil porosity and patch area. Soil porosity is significantly positively affected by plant cover, litter cover, soil texture, but infiltration capability is reduced by increasing amounts of coarse fragments bigger than 60 mm and especially by the area of outcrop, which is positively correlated with altitude and slope gradient. Due to the fact that in study area the content of coarse fragments and area of outcrop increase by increasing altitude and slope gradient, the area for infiltration decreases and also coarse fragments intercept raindrops reducing crust formation on the soil surface, which decreases infiltration. Field observation of soil surface conditions indicated that there was no surface crust at these sites, which is consistent with this interpretation.

Increasing gravel content is also associated with decreasing soil nutrient availability, infiltration index, stability index, and LOI, which means that these sites support less biomass, canopy cover, and litter cover. It was supposed that there would be a positive relationship between infiltration index and coarse material content of topsoil (0–10 cm); however, the relationship was negative ($r = -0.42$). This may be due to increasing gravel content and outcrops in parallel with increasing slope gradient, which is associated with increased gravity and water flow. Therefore, the overall relationship between coarse fragments and infiltration index became negatively related.

In a robust and healthy rangeland it is anticipated that LOI, which is assumed to be a reliable indicator for vegetation cover, should have close relationships with stability, infiltration, and nutrient cycling indices and also with organic carbon and total nitrogen. These relationships occurred for subareas 1 and 3, but not for subarea 2. Also it is reasonable to expect that an area with a high mean value for LOI (high vegetation cover) has a high mean value for stability index. This occurs for subareas 1 and 3, but not for subarea 2. The absence of these expected relationships may be a good indicator of land degradation or a low capability for production in this subarea. A strong correlation between LOI and stability index does not necessarily mean that the rangeland stability is mainly governed by vegetation cover. Tongway and Hindley (1995) concluded that stability index is related to several soil surface characteristics including soil surface feature consisting of vegetation cover, litter cover, cryptogram cover, and material resistant to erosion particularly coarse fragments and together with the soils inherent resistance to erosion. Hence in this study area, due to lack of cryptogam cover, the stability index is governed mainly by plant materials and coarse fragments on the soil surface.

Five States can be considered for considering relationships between stability index and LOI as illustrated in Fig. 3. For State 1, when there is no significant correlation between stability index and LOI, stability index is governed by a combination of different soil surface characteristics with no dominant effect from anyone of them. This situation can occur when the study area is not homogenous. State 2 indicates

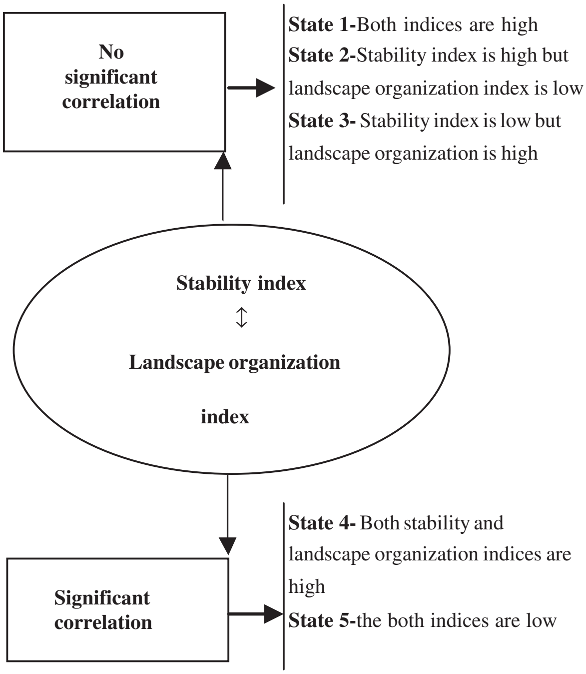

Fig. 3. Shows the five States considering relationships between stability index and landscape organization index.

that a protector other than plant cover and litter cover mainly governs stability. State 3 is representative of rangelands in which stability is mainly governed by vegetation cover but either eroding factors are strong or the soil is inherently sensitive to erosion. State 4, when there is significant correlation between stability index and LOI, it is representative of a robust and productive rangeland, which at the same time is managed wisely. State 5 represents a weak and sensitive rangeland but whether it is overgrazed or has an inherently low capability must be determined from soil properties.

This interpretation is well supported by significant positive relationships between foliage cover and stability and foliage cover and LOI ($r = 0.62$ and $r = 0.60$, respectively). On the basis of this interpretation subarea 3 with the highest significant correlation coefficient between LOI and stability index and the highest mean value (66) for stability index and the highest mean value (0.52) for LOI can be nominated as a good representative for State 4, which represents a robust and highly productive rangeland.

All pairwise correlations coefficients for NCI are highly significant for the three subareas. As discussed earlier the effects of slope class, aspect, and vegetation type were highly significant for this index. Therefore, it is expected that this index will be a robust predictor of soil productivity and rangeland production. The most predictive multiple regression equation suggests that nutrient cycling, stability, and landscape

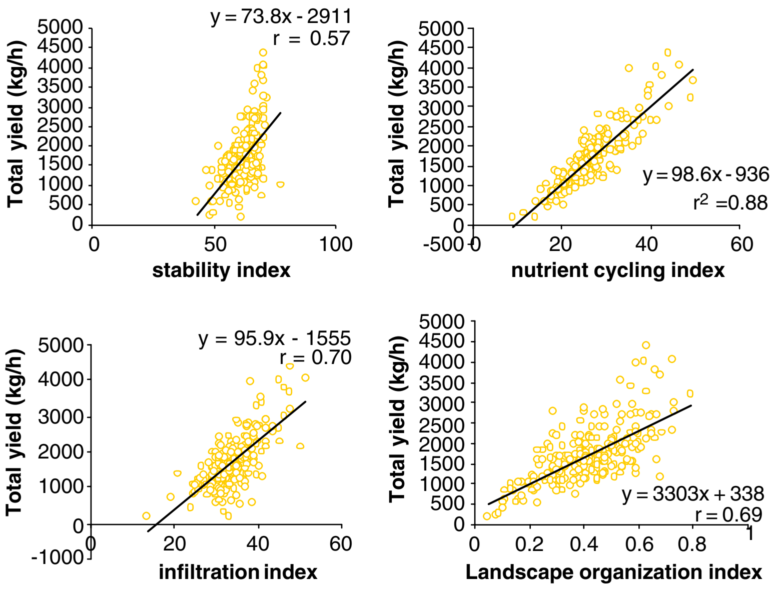

Fig. 4. Show the relationships between landscape function indices and total yield production.

organization indices were the best predictors of rangeland total yield production but not for herbaceous plant production (Fig. 4). It shows a very good fit to a linear regression between total yield and NCI with a much smaller standard deviation compared to other indices. However, one can not neglect the important roles of stability, infiltration, and LOI indices especially for conservation purpose which is different from simply maximizing plant and animal productivity.

3.3. Application of LFA index

Among the LFA indices proposed by Tongway and Hindley (1995, 2004) NCI as an integrative indicator explains the variation in soil productivity of rangelands for both site capability assessment and monitoring purposes better than does any other variable. Consequently, this index may be taken into consideration in range capability assessment and range management as a surrogate instead of using large number of individual soil properties. As a basis of conservative management of rangeland, both infiltration and stability indices should be included so as to include soil qualities relating to resistance to erosion and ability to absorb rainfall. However, for the following reasons infiltration and stability index are not well suited to their proposed purpose in the LFA method in this study area:

1. Soil surface characteristics involved in the assessment of infiltration index include perennial grass basal cover and shrub foliage cover, litter cover, soil surface nature, surface resistance to disturbance, slake test, and soil texture. All these observations relate to the soil surface in order to generate an infiltration index.

However, a high value for infiltration index does not necessarily means that the particular site can store the infiltrated water. Therefore, evaluation requires another index to describe the soil profile characteristic that relates to water storage capacity, which depends on depth of profile, soil texture of whole profile, and gravel content, and which is not expressed by indices based on soil surface properties or vegetation characteristics (LFA method) (Tongway and Hindley, 1995, 2004).

2. The value of stability index is integrated from several observations of the soil surface, but a high stability index does not necessarily always mean that the site has high production potential. Only if a high stability index value coincides with high NCI and LOI will the high stability index be associated with extensive vegetation cover, reflecting high soil productivity. Therefore, although it is a useful index to assess soil stability, it is not simply related to soil productivity and range plant production. Consequently the stability index can not be employed in isolation as a predictive indicator for site capability assessment of rangelands unless it can be shown to be closely related to plant cover or LOI.

4. Conclusion

The relationships between soil properties and landscape attributes determined by this research indicate that landscape attributes including slope, aspect, and elevation affect plant growth through indirect influences involving soil properties. Thus landscape attributes indirectly have a strong impact on range production and site stability. We found that:

1. An increasing slope gradient can influence all soil properties especially stability index, therefore, range sites with a slope gradient more than 56% should not be grazed by livestock due to erosion risk.
2. Lower soil temperature and less moisture evaporation on a north-facing slope (shady aspect) results in less soil organic matter decomposition and consequently more organic carbon and total nitrogen accumulation in the soil. Consequently the soil nutrient pool and general fertility on north-facing slopes is greater than on south-facing slopes.
3. NCI, which is indicative of the efficiency of the nutrient cycling process, explains the variation in soil productivity of rangelands better than does any other variable. Therefore, this index may be taken into consideration in range capability assessment and range management as a surrogate instead of using large number of individual soil properties.

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