

**EVALUATE SOIL QUALITY AND PASTURE BIOMASS YIELD
RELATIONSHIP IN THE SEMI-ARID REIGONS OF THE
WESTERN AZERBAIJAN, IRAN**

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ABSTRACT

Healthy soils support diversity of terrestrial vegetative ecosystems. However, soil quality degradation often led to affect soil productivity and unable to support sustainable biomass production. The study was conducted to better understand the relationship between pasture biomass yields and soil quality in the semi-arid natural grasslands of the Shohada-Valley, Western Azerbaijan Province of Iran. With the identification and delineation of the mapping units, a composite base map was prepared to combine maps of four directions, five classes of slope degrees, and several vegetation types using geographic information system (GIS) on a 1:50,000 scale. Composite soil sample was randomly taken from 0 to 30 cm depth and selected soil chemical and physical properties were determined by using standard methods of analysis. The pasture yield, consists of herbaceous plants and small shrubs at their flowering stage, was determined. Principle Component Analysis (PCA) and step-wise multiple regressions were performed to identify soil quality (SQ) core indicators related to biomass production. Based on 28 delineated mapping units, the mean values of soil landscape, stability, infiltration rates, and nutrient indices were calculated as 0.8, 76.9, 57.1 and 69.1, respectively. Mean total biomass yield was determined 1.54 Mg/ha. By using the PCA, three components were identified having a latent root more than one, which accounted for 78% of the SQ variability. The indicator variables for calculating the soil quality index (SQ_{Index}) werelandscape organization index (LO_{Index}), nutrient cycling index (NC_{Index}), and salinity and compaction (bulk density, pb) were determined. The calculated SQ_{Index} significantly and linearly accounted for 64% of variability in measured pasture yield. Likewise, the predicted pasture yield based on SO_{index} significantly and linearly correlated with field-measured pasture yield, by accounting for 63% of the variability or vice-versa. Results suggested that that the SQ_{index} model is very usable to provide a reliable estimation

of pasture biomass production in the semi-arid and cold semi-steppe habitats for such regions in the world.

Keywords: Plant, soil properties, GIS, principal component analysis, nutrient index

INTRODUCTION

Maintaining a healthy soil is important for economic crop production with enhanced agro-ecosystem services. Soil degradation affects soil quality and subsequently, increases the widespread susceptibility of environmental hazards. Soil quality can be defined as the ability of the soil to perform essential functions that provide soil management objectives (De la Rosa, 2005). Soil quality, whether it is static and reflects differences arising from the natural soil forming processes and factors or is dynamic which reflects the spatial and temporal variations in response to management practices (Erkossa et al., 2007, Kinyangi, 2007). Thus, the term of soil quality is generally discussed in terms of its current performance within terrestrial ecosystems (Lety et al., 2003; Karlen et al., 2003).

Doran and Parkin (1996) proposed the soil parameters like texture, depth and root development, bulk density (ρ_b), infiltration rate, water holding capacity, organic matter, nitrogen, pH, electrical conductivity (ECe), available phosphorus, exchangeable potassium, soil microbes and the mineralization capacity are important determinants of SQ. Moody et al (1997) suggested ECe, pH, clay content, texture, organic matter, and cation exchange capacity as parameters that showed potentiality to provide nutrients for crop production. Andrews and Carroll (2001) reported that soil structures, compaction, water erosion, phosphorus, depth, moisture potential, and salinity are important variables to evaluate land potentiality. Arshad and Martin (2002) suggested the soil properties that are indicative of the physical and chemical degradation of soil [such as depth, water holding capacity (WHC), electrical conductivity (ECe), pH, organic matter, slope, altitude, climate and hydrological properties] are important to assess SQ. In contrast, Bockstaller and Girard in (2003) introduced SQ indices based on the interaction between the soil and the environment in which a large number of soil properties (such as pH, ρ_b , available phosphorus and nitrogen, total organic carbon, and heavy metals) that are effective to sustain higher crop production.

Islam and Weil (2000) predicted SQ based on those intermediate soil properties (e.g. microbial biomass, total organic carbon, soil aggregate stability, etc.) that are neither permanently stable (e.g. slope, texture, depth of fragipan, etc.) nor ephemeral (e.g. pH, moisture content, available nutrients, etc.), but consistently impacted by management practices. They reported that soil management practices, such as, conservation tillage, crop rotation, cover crops, organic

amendments and improved soil fertility had greater impacts on 13 SQ properties, which were used as a minimum orthogonal dataset to assess SQ Index. Similarly, Aziz et al (2011) used several intermediate biological, chemical and physical properties of soil to calculate SQ and have shown a significant correlation with soil functions, such as carbon sequestration under different management practices.

Most of the studies suggested that a minimum dataset of soil indicators are suitable to evaluate and/or predict SQ (Doran and Parkin 1996, Moody et al. 1997, Andrews and Carroll 2001, Muir 2001, Bockstaller and Girardin 2003, Aziz et al. 2011). However, the information on SQ that is significantly affected by the natural and diverse- and managed vegetation ecosystems is limited. We hypothesize that land productivity associated with the plant growth and biomass production is the function of those sensitive soil properties which consistently affect SQ. Therefore, our study was conducted to evaluate grassland SQ in the semi-arid regions of the Western Azerbaijan province of Iran. In this study, modeling of land factors and soil properties was rated quantitatively and integrated to calculate for SQ as a predictor of pasture biomass production potential of the lands.

Materials and methods

Location of the study area

The study area is located in the Shohada-Valley of the Urmia city in Western Azerbaijan Province of Iran. The study area was selected with extensive pasturelands covers about 255 ha and extends from the 37°15' to 37° 20' N latitudes and 45°05' to 45°10' E longitudes (**Fig. 1**). Minimum and maximum heights of 1500 and 2100 meters, respectively were higher than mean sea level. Mean annual precipitation is 367 mm with 15% of the rain falls in April. Mean annual temperature is 8°C with a maximum value of 14.5°C in the month of July and minimum value of -2.5°C in the month of December.



Fig 1: Location of the study area in the West Azerbaijan province of Iran

Research method for mapping

The slope maps of the study area were prepared by using topographic map at 1:50,000 scale into five different classes, including 0 to 3, 3 to 10, 10 to 32, 32 to 56 and higher than 56%, respectively. Existing vegetation types at the site were identified by the interpretation of the aerial photographs with a 1:55,000 scale and followed by supervised field studies. The mapping units were obtained by the integration of all these maps into the GIS. A relatively homogenous geological map with 28 units was created from the integration of slope percentage, direction maps, and the type of vegetation (**Fig. 2**).

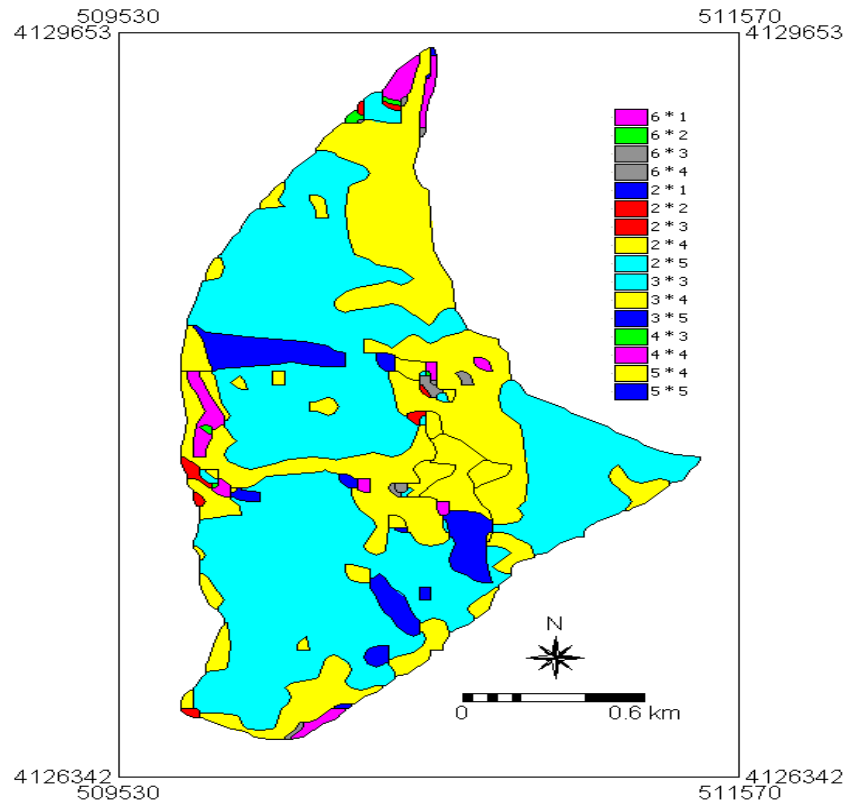


Fig 2: The homogenous geological map

Soil processing and analysis

Composite soils were taken based on units delineated in the homogenous geological map at 0 to 30 cm depth for detailed lab analysis. Field-moist soil samples were air-dried at room temperature (~ 25°C) for a 15-day period followed by grinding with a porcelain mortar and pestle, and sieved through a 2-mm mesh.

The ECe and pH were determined by following Rhoades (1996). Soil TOC concentration was determined by following the Walkley–Black wet oxidation procedure, and the total nitrogen (TN) was determined by using the micro-kjeldahl digestion and distillation procedure (Bremner and Mulvaney 1982). Soil aggregate properties (size, shape and stability), texture, depth, and slake test were determined by Tongway and Hindley (2004). The Tongway and Hindley method (2004) was also used for Landscape Function Analysis (LFA). In the LFA method, a transect that shows the properties of each land mapping unit was considered with the 3 m width x 50 m length. Surface soil condition was used to calculate the stability index, infiltration index and

nutrient cycling index, respectively. These three indicators were obtained by combining few sub-indicators for determining clusters of soil conditioning indices(Fig.3) that was finally used to calculate the SQ index (Equation 1).

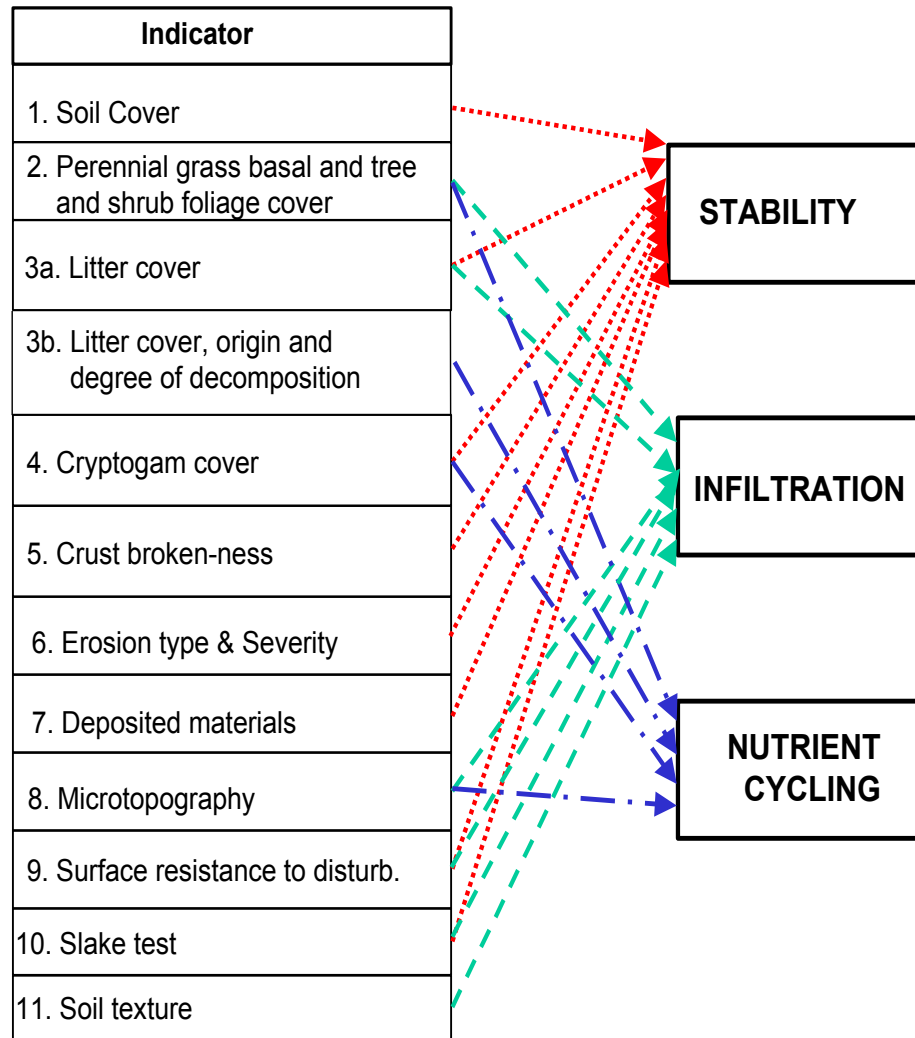


Fig 3: The combination of indicators into clusters of soil property indices.

Total pasture yield (total shoot biomass of both herbaceous plants and shrubs) was determined randomly over the years at maximum vegetative growth (flowering stage)of the dominant plant species by direct biomass harvesting method (Bonham, 1989).

Statistical analysis of soil quality

The SQ_{index}, calculated based on core indicator properties, was calculated by using the **Equation 1** and Principal Component Analysis (PCA):

$$SQ_{index} = \sum(P_i S_i) \quad (1)$$

Where, the S_i is the datum of each variable and P_i is the weight of each variable.

The variance that explained in the total variable of each vector is proportional to eigen value or latent root of variance in the PCA method. The vectors which show the latent root more than 1 indicates that the “system properties are better than the main variables that act individually”. Therefore, only vectors which shown the latent root more than 1 were considered to select the variables. Then, by using stepwise multiple regression analyses, the selected soil variables and the plant biomass yield were considered as independent and dependent variables, respectively.

To evaluate the accuracy and deviation of the mathematical model, the Mean Absolute Error (MAE) (equation (2)) and the Mean Bias Error (MBE) (equation (3)) were calculated and applied, respectively.

$$MAE = \frac{1}{n} \sum_{i=1}^n |f_i - y_i| \quad (2)$$

$$MBE = \frac{1}{n} \sum_{i=1}^n (f_i - y_i) \quad (3)$$

Where the f_i is the estimated value and y_i is the measured value.

The Mean Absolute Percentage Error (MAPE) (equation (4)) was used to have a better understanding of the model error.

$$M = \frac{1}{n} \sum_{t=1}^n \left| \frac{At - Ft}{At} \right| \quad (4)$$

Where the At is the measured value and Ft is the estimated value. Modeling Efficiency (EF) was calculated by equation (5):

$$(5) \quad EF = \frac{\sum_{i=1}^n (Q_i - \bar{Q})^2 - \sum_{i=1}^n (P_i - Q_i)^2}{\sum_{i=1}^n (Q_i - \bar{Q})^2}$$

Where the P_i is the estimated value, Q_i is the measured value, and Q is the mean of measured value.

The maps contain the percentage and direction of slope were created by digitizing the curves in the GIS and the ILWIS software[®].

Results and Discussion

Statistical properties of topsoil indices

Experimental data showed that the mean values of the landscape index, stability index, infiltration index and nutrient index were 0.83, 76.9, 57.1 and 69.1, respectively. The results of the landscape index analyzing including stability, infiltration, nutrient cycling and soil organization were 77, 57, 69 and 83%, respectively. The effect of the soil and vegetation properties on infiltration, stability and nutrients indices is shown in **Fig. 4**.

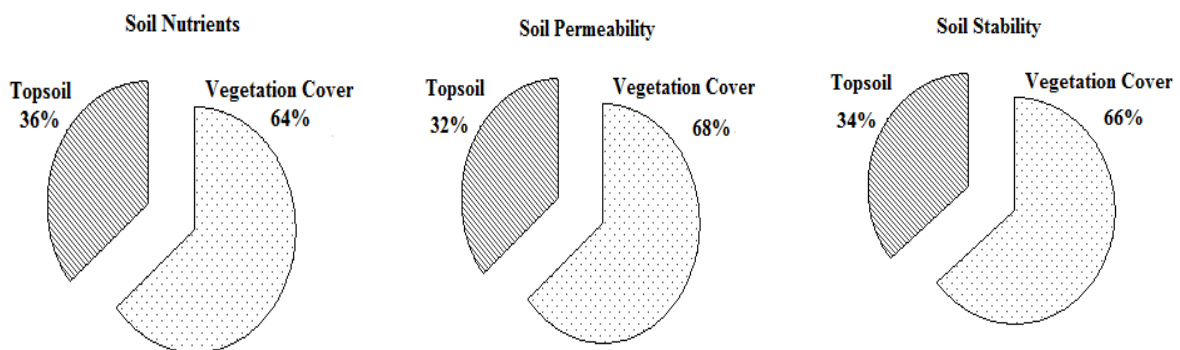


Figure 4: The effect of topsoil and vegetation properties on the nutrient, infiltration rate and stability indices.

Among the 17 soil factors, 8 variables including soil organization, nitrogen content, organic carbon content, the infiltration rate, nutrients cycling, field moisture capacity, pb and ECe were selected as the minimum dataset of SQ to predict for pasture yield (**Table2**).

Table 2: Correlation coefficient of soil variables with pasture yields

Variables	vs. Pasture yield (kg/ha)	Correlation coefficient
The selected variables		
Soil organization index		0.63**
Total nitrogen content		0.60**
Organic carbon content		0.5**
Infiltration rate		0.52**
Nutrients cycling		0.64**
Bulk density		0.39*
Electrical conductivity		-0.36*
Stability index		-0.08
pH		-0.13
Available P		0.08
Exchangeable K		-0/20
The omitted variables		
Sand		0.35
Silt		-0.34

Clay	-0.12
Moisture content at permanent wilting point (15 bar)	-0.31
Moisture content at field capacity (333 cbar)	-0.39

** and* indicate correlation is significant at $p \leq 0.01$ and 0.05 levels, respectively

According to the results of the PCA analysis, among 8 components of the analysis, three vectors which have the Latent Root greater than 1, explained about 78% of the variance of data. The soil organization index and nutrient cycling index as the members of the first vectors, the field moisture capacity and bulk density as the members of the second vector, and electrical conductivity as the third vector, were the most important factors (**Table 3**). Based on the analysis, the minimum data-set on variables that needed to calculate soil quality are presented in **Table 4**.

Table 3: Main components, latent root of variance and change (%) for each component.

Variables	Main components		
	λ_1	λ_2	λ_3
Soil organization index	<u>0.764</u>	0.136	-0.122
Total nitrogen	0.667	0.478	0.269
Total organic carbon	0.666	0.012	0.596
Infiltration rate	0.593	0.530	-0.189
Nutrient cycling	<u>0.715</u>	0.175	-0.117
Field moisture capacity	-0.202	-0.653	-0.084
Bulk density	0.169	<u>-0.967</u>	0.005
Electrical conductivity	-0.202	0.043	<u>0.904</u>

Latent root of variance	1.316	2.405	2.487
Individual change of each component (%)	16.453	30.060	31.09
Total change of each component (%)	77.601	61.148	31.088

Table 4: The minimum variables to evaluate soil quality index in the grasslands

Soil functions	Minimum variables
Soil Fertility	Nutrient cycling index (LUT), Organization index (LOI), Salinity (ECe)
Water infiltration	Soil bulk density (ρ_b)

The method of calculating of soil quality index according related to total biomass production (TY) is shown in **Table 5**. According to equation 1, **S** coefficient that was used in the columns 2, 4, 6, and 8, and the ρ_i coefficient in columns 9, 10, 11 and 12 is obtained from the **Table 4**. The results which lead to measuring of soil quality index predicting plant biomass production are shown in the last column of the **Table 5**. However, Islam and Weil (2000) selected only 13 factors to evaluate soil quality. In addition to the physical, chemical and biological properties, the factors, such as LFA has been used in this study, whereas it has not been considered to use in previous studies. Bockstaller and Girardin (2003) used the soil chemical properties, Arshad and Martin (2002) used the land shape or topography, Andrews and Carroll (2001) used the soil physical properties, Doran and Parkin (1996) used the soil biological properties, and Moody et al (1997) used the soil moisture content in determining soil quality. It should also be noted that few other variables indirectly affected on soil quality and plant biomass yield. However, these variables significantly impacted plant biomass production (Andrews and Carroll 2001, Bockstaller and Girardin 2003).

Table 5: The method of calculating of soil quality index for total biomass production in the study area

	1	2	3	4	5	6	7	8	9	10	11	12	13
Working units	-	$= -0.359x + 1.08$	-	$= 0.013x - 0.2157$	-	$= 1.219x - 0.158$	-	$= 1.1676x - 0.6348$	$= (2) * 0.31$	$= (4) * 0.20$	$= (6) * 0.19$	$= (8) * 0.30$	$= (9) + (10) + (11) + (12)$
	EC	S EC&TY	NUTR	S NUTR&TY	LOI	S LOI&TY	BD	S BD&TY	SQI EC&TY	SQI NUTR&TY	SQI LOI&TY	SQI Bd&TY	ΣSQI TY
1	0.4	0.93	61.75	0.59	0.84	0.87	1.2	0.77	0.29	0.12	0.16	0.23	0.80
2	0.2	1.00	68.94	0.68	0.90	0.94	1.19	0.75	0.31	0.14	0.18	0.23	0.85
3	0.4	0.93	79.52	0.82	0.95	1.00	1.31	0.89	0.29	0.16	0.19	0.27	0.91
4	0.4	0.93	68.98	0.68	0.92	0.96	1.27	0.85	0.29	0.14	0.18	0.25	0.86
5	0.5	0.89	69.72	0.69	0.90	0.94	1.23	0.80	0.28	0.14	0.18	0.24	0.83
6	0.5	0.90	65.91	0.64	0.84	0.87	1.21	0.78	0.28	0.13	0.16	0.23	0.81
7	0.4	0.95	71.42	0.71	0.88	0.91	1.21	0.78	0.30	0.14	0.17	0.23	0.85

8	0.4	0.93	71.74	0.72	0.88	0.91	1.36	0.95	0.29	0.14	0.17	0.29	0.89
9	0.5	0.92	71.86	0.72	0.90	0.94	1.31	0.89	0.28	0.14	0.18	0.27	0.87
10	0.4	0.93	70.01	0.69	0.88	0.91	1.25	0.82	0.29	0.14	0.17	0.25	0.85
11	0.8	0.80	64.42	0.62	0.89	0.93	1.22	0.79	0.25	0.12	0.18	0.24	0.78
12	0.5	0.90	69.41	0.69	0.89	0.93	1.24	0.81	0.28	0.14	0.18	0.24	0.84
13	0.5	0.91	67.69	0.66	0.77	0.78	1.31	0.89	0.28	0.13	0.15	0.27	0.83
14	0.5	0.90	68.62	0.68	0.85	0.88	1.3	0.88	0.28	0.14	0.17	0.26	0.85
15	0.5	0.89	68.79	0.68	0.90	0.94	1.4	1.00	0.28	0.14	0.18	0.30	0.89
16	0.8	0.81	70.42	0.70	0.89	0.93	1.29	0.87	0.25	0.14	0.18	0.26	0.83
17	0.9	0.75	71.50	0.71	0.74	0.74	1.22	0.79	0.23	0.14	0.14	0.24	0.75
18	0.5	0.89	66.36	0.65	0.87	0.90	1.27	0.85	0.28	0.13	0.17	0.25	0.83
19	0.6	0.87	67.50	0.66	0.72	0.72	1.25	0.82	0.27	0.13	0.14	0.25	0.79
20	0.4	0.93	70.66	0.70	0.93	0.98	1.31	0.89	0.29	0.14	0.19	0.27	0.88
21	0.6	0.86	67.70	0.66	0.86	0.89	1.31	0.89	0.27	0.13	0.17	0.27	0.84
22	0.6	0.86	75.60	0.77	0.90	0.94	1.34	0.93	0.27	0.15	0.18	0.28	0.88
23	0.3	0.98	72.60	0.73	0.89	0.93	1.33	0.92	0.30	0.15	0.18	0.28	0.90
24	0.4	0.93	81.50	0.84	0.85	0.88	1.27	0.85	0.29	0.17	0.17	0.25	0.88

25	0.3	0.99	62.60	0.60	0.72	0.72	1.25	0.82	0.31	0.12	0.14	0.25	0.81
26	0.3	0.97	90.30	0.96	0.94	0.99	1.26	0.84	0.30	0.19	0.19	0.25	0.93
27	0.3	0.99	85.90	0.90	0.92	0.96	1.28	0.86	0.31	0.18	0.18	0.26	0.93
28	0.4	0.93	74.20	0.75	0.88	0.91	1.27	0.85	0.29	0.15	0.17	0.25	0.87

EC= Soil salinity, S EC & TY= Composite index of soil salinity and total yield, S NUTR & TY= Composite index of nutrient cycling and total yield, S LOI & TY = Composite index of organization index and total yield, S ρ_b & TY= Composite index of bulk density and total yield, SQIEC & TY= Soil quality index of soil salinity and total yield, SQI NUTR & TY= Soil quality index of nutrient cycling and total yield, SQI LOI&TY= Soil quality index of landscape organization index and total yield, SQI ρ_b & TY= Soil quality index of bulk density and total yield, and Σ SQI TY= Soil quality index of total yield.

The mean total plant biomass yield was recorded 1.53 MgDM/ ha. Based on the biomass production identified on each mapping unit, the values of soil quality index that were more than 0.8 suggested the optimum soil condition for higher plant production. The relationship between the soil quality index and the total biomass yield is shown in Figure 5. The coefficient of determination (R^2) suggested that the calculated soil quality significantly accounted for 63% of the variability in total biomass yields.

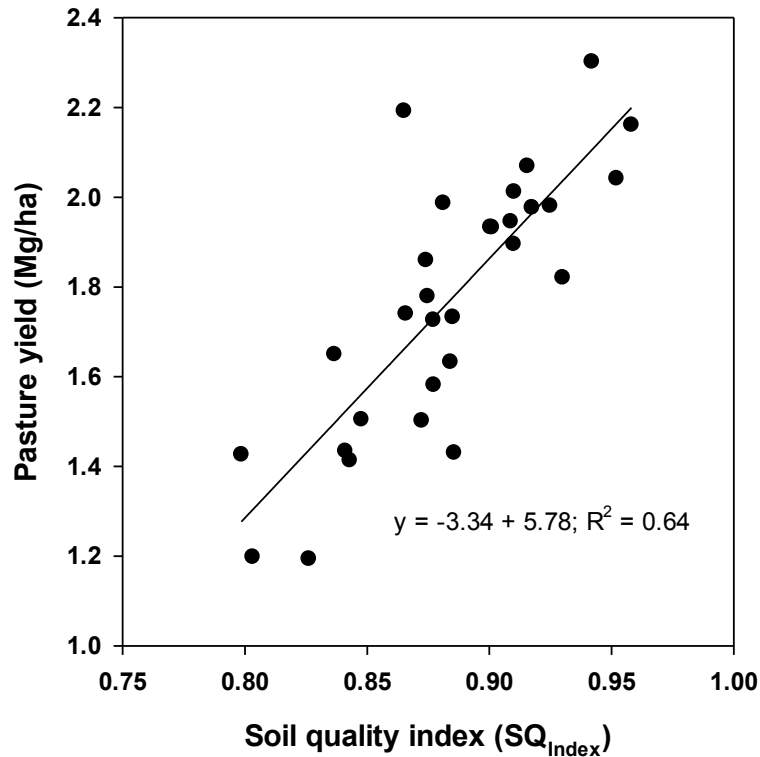


Figure 5: Relationship of soil quality index with measured pasture biomass yield.

The significant relationship between actually measured plant biomass yield and the predicted yield based on the calculated soil quality, suggested that 64% of the variability in the actually measured biomass yield can be accounted by using soil quality index (**Figure 6**). The MAE and MBE for assessing the accuracy and deviation of the mathematical model were calculated for 139.9 and -0.02, respectively. This indicated that the predicted model was slightly underestimated for describing the relationship between soil quality and plant productivity with a margin error of $\pm 8\%$. However, the modeling efficiency (**Equation 5**) was determined 0.66, which suggested the goodness of the fit of the model. Therefore, both static and intermediate soil properties (such as nutrient cycling and N content) can be used in combination for the assessment and monitoring of soil quality to better understand the soil ecosystems functionality.

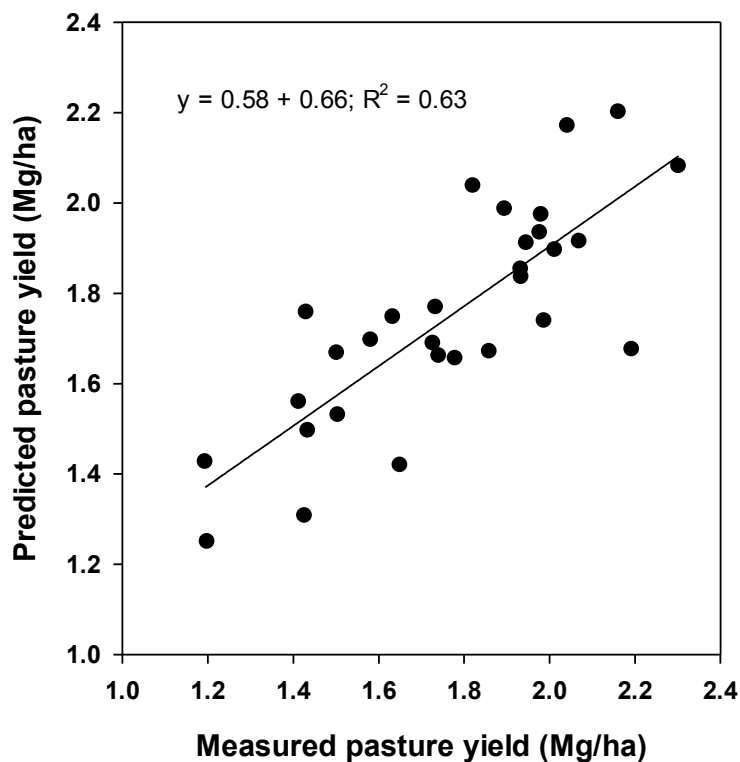


Figure 6: Relationship between measured-and predicted pasture biomass yields based on soil quality index.

CONCLUSION

Among the 17 measured variables, 8 variables including soil organization, total nitrogen and organic carbon content, infiltration, nutrient cycling, field moisture capacity, bulk density and salinity were selected as the core factors to predict plant production. However, soil pH and phosphorus and potassium contents were excluded due to weak correlations with the total plant biomass production. A lack of significant change in these variables may have responsible to exert significant effects on the plant biomass production. The soil organization index had shown intermediate state of variations, as it did not change over time to account the natural effects. Moreover, it was not identified as a dynamic property because it did not show any temporal changes regional climate change effects. The calculated soil quality index has shown less deviation and offers better interpretation of the soil ecosystem compared with that of the linear models with a single predictor variable.

REFERENCES

- Andrews S.S. and C.R. Carroll. 2001. Designing a decision tool for sustainable agroecosystem management: soil quality assessment of a poultry litter management case study. *Ecol Appl.* 11, 1573–1585.
- Arshad, M.A. and S. Martin.2002. Identifying critical limits for soil quality indicators in agro-ecosystems. *Agric Ecosys Environ* 88, 153–160.
- Aziz, I., M. Ashraf., T. Mahmood, and K.R. Islam (2011) Crop rotation impact on soil quality. *Pakistan Journal of Botany*, 43: 949-960.
- Bockstaller, C. and P. Girardin. 2003. How to validate environmental indicators. *Agric. Sys.* 76, 639-653.
- Bonham, C. D. 1989. Measurements for terrestrial vegetation. 338p, John Wiley & Sons, NY.
- Bremner J.M. and C.S. Mulvaney.1982. Nitrogen – total. In: *Methods of soil analysis, Part 2* (ed. AL Page), SSSA & ASA, Madison, WI, USA. pp. 595–624.
- De la Rosa, D. (2005). Soil quality evaluation and monitoring based on land evaluation. *Land Degrad Develop* 16, 551–559.
- Doran, J.W. and T.B. Parkin. 1996. Quantitative indicators of soil quality: a minimum data set. In: Doran, J. W. and Jones, A.J. (Eds.), *Methods for Assessing Soil Quality*. Soil Science Society of America, Special Publication, 49: 25–37.

Erkossa, T., F. Itanna, and K. Stahr. 2007. Indexing soil quality: a new paradigm in soil science research. *Aust J. Soil Res* 45, 129–137.

[Islam](#) K.R. and [R.R Weil](#). 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh [Agric Ecosys Environ](#) 79,9–16.

Karlen D.L., S.S. Andrews and J.W. Doran. 2001. Soil quality: current concepts and applications. *Adv Agron* 74, 1 –40.

Kinyangi, J. 2007. Soil health and soil quality: a review. Draft publication. Available on: <http://www.cornell.edu.org>; Accessed on: www.worldagroinfo.org. Accessed 15 Feb 2010.

Larson, W.E. and F.J. Pierce 1994. The dynamics of soil quality as a measure of sustainable management. pp. 37-51. In J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.), *Defining Soil Quality for a Sustainable Environment*. SSSA Spec. Pub. No. 35, Soil Sci. Soc. Am., Am. Soc. Argon., Madison, WI.

Moody, P.W., S.A. Yo, and R.L. Aitken. 1997. Soil organic carbon, permanganate fractions, and the chemical properties of acidic soils. *Aust. J. Soil Res* 35:1301-1308.

Muir, A. 1960. Soil survey in Britain. *Soil Survey of Great Britain Report 13 (1960)*, 1-9. Agricultural Research Council.

Rhoades, J.D. 1996. Salinity: electrical conductivity and total dissolved solids. In ‘Methods of soil analysis. Part 3: Chemical methods’. (Ed. DL Sparks) pp. 417–435. (ASA, SSSA: Madison, WI)

Tongway D.J. and N. Hindley. 1995. *Manual for assessment of soil condition of tropical grasslands*. CSIRO, Canberra, Australia.p. 60.

Van Gool, D. and Moore, G. 1998. *Land Evaluation Standards for Land Resource Mapping: Guidelines for Assessing Land Qualities and Determining Land Capability in South-West Western Australia*, Resource Management Technical Report No. 181, Natural Resource Assessment Group, Agriculture Western Australia, Perth.