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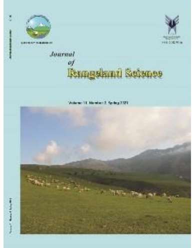

Research and Full Length Article:

Effect of Soil Properties on Above-ground Net Primary Production in Moghan-Sabalan Rangelands, Iran

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Abstract. The aim of this study was to investigate the relationship between total community and Plant Functional Types (PFTs) Aboveground Net Primary Production (ANPP) with soil variables. Sampling done in two altitude gradients (20-3300m) and 25 sites at the rangelands of the northern Ardabil province in 2016. In each site, PFTs ANPP and soil were sampled. In laboratory soil variables including Soil Texture, Dispersible Clay, Bulk Density, Volumetric Soil Water Content, Saturation Percent, pH, EC, Organic Matter, Particulate Organic Matter, Calcium, Magnesium, Phosphorous, Sodium, Soluble Potassium, Exchangeable Potassium, Lime and Carbonate were measured. Cluster analysis was used to group sites based on soil variables. ANOVA and Tukey tests were employed to compare the value of ANPP and soil variable at different groups resulting from cluster analysis. Then, linear regression was used to investigate relationship between ANPP and soil variables. Based on cluster analysis, 25 sites were divided in four soil types and results showed that the value of PFTs and total ANPP and 26 soil variables from 37 soil variables had significant differences between grouping sites. Regression model showed that SK and P in first depth of soil were effective on grasses (R^2=0.51), VWC and P in the first depth and EK and Mg in the second depth were effective on forbs ANPP (R^2=0.61), Clay, VWC, Mg and POM in the second depth were effective on shrubs ANPP (R^2=0.71) and pH in the first depth, Sand and POM in the second depth were effective on total ANPP (R^2=0.76). According to the obtained models, ANPP changes can be predicted by soil variables. Also, based on the result, PFTs can be a suitable indicator for soil condition of rangeland. So, the results of the present study can be used to refine rangelands in this area and even to extend them to other areas.

Key words: Plant functional type, Forbs, Grasses, Shrubs, Soil properties

Introduction

Aboveground Net Primary Production (ANPP) is the total energy stabilized during the photosynthesis process, minus the loss of respiration, which is stored as plant tissue (Liang *et al.*, 2015). Estimating ANPP is an important factor in assessing ecological relationships and processes, wildlife habitat, forage availability and fire fuel loads (Boyda *et al.,* 2015). The harvest of plants current year growth at the maximum growth is the most commonly and easiest way to estimate ANPP (Boyda *et al.*, 2015). But estimating ANPP by cutting and weighing is time-consuming, destructive and costly (Arzani and Abedi, 2015). This has caused the studies to substitute direct measurement for estimating ANPP. The value of ANPP in rangelands related to various environmental factors (Fang *et al.*, 2016; Liu *et al.,* 2016). In order to estimate the ANPP under the effect of environmental factors, it is necessary to investigate the relationship between ANPP and these factors (Pournemati *et al.*, 2017). Soil is one of the most effective environmental factors on ANPP variation (Li *et al.,* 2020). There are strong relationships between soil quality and ANPP (Paz-Kagan *et al.,* 2014). Among environmental factors, soil is the most important factor that is effective on ANPP and is a function of climate, organisms, topography and time (Ward *et al.,* 2017). Chemical and physical properties of soil are important and have a key role in the formation and structure of plant communities (Bednarek *et al.,* 2005).

A natural or managed ecosystem has high plant productivity when its soil quality is high (Karlen *et al.,* 1997). However, when soil is degraded and its quality is low, the ability to support ANPP is low (Paz-Kagan *et al.*, 2014). For efficient ANPP in rangelands, it is necessary to be aware of the characteristics of the rangeland soil because the soil characteristics reflect the limitations of the ecosystem (Newman and Hart, 2015). Soil texture and soil nutrient properties have an important role in determining the composition of the community relative and the total ANPP (Zareii *et al.,* 2010). The soil properties influence plant production by affecting soil water content (Collins and foster, 2008). Austin *et al.* (2004) reported that in arid environment, value of ANPP is higher in fine textured soils because of the reduced evaporation. Similarly, in the area with more precipitation, ANPP is greater in fine textured soils because of the increased water-holding capacity. However, there is a hypothesis for arid and semi-arid regions; rangelands with coarse-textured soils have more net primary production than areas with fine texture (Khalil *et al.,* 2015). Plants for growth and development absorb water and nutrients by their roots from the soil and storing them in the root. For this reason, the growth of plants strongly depends on the soil characteristics and different plant functional type (PFTs) responses and expresses their tolerance in a different way (Tron *et al.*, 2015).

PFTs are species groups with similar characteristics that respond to environmental factors and biological controls, and have similar effects on ecosystem function (Wullschleger *et al.,* 2014; Sharafatmandrad *et al.,* 2014). Moreover, PFTs have different responses to changes in soil properties and their distinctive adaptive strategies to the environment (Wang *et al.,* 2017). The study of ANPP based on PFTs is important for predicting vegetation changes and ecosystem function in a climate change (Iturrate-Garcia *et al.,* 2016). One of the differences between PFTs is a type of roots (Wang *et al.,* 2020). Wang *et al.* (2017) investigate above and below-ground responses of plant functional types to deep soil heating and surface soil fertilization. Their results showed that sedges had the strongest response to deep soil heating although shrubs and grasses respond to fertilization. They suggested that grasses have the highest root plasticity, which enables them to be more competitive in rapidly changing environments. Dadjou *et al.* (2017) examined relationships between plant functional types and soil factors. They concluded that grasses are related with Silt, Ec, Ca, K, POM and SOM, shrubs relation with pH, Ec, P and POM and forbs are related with Clay, Mg, pH, TNV, EC, Ca, POM and SOM.

In view of what has been stated, the necessity and purpose of the present study are summarized as following sections.

1. Moghan-Sabalan rangeland with different ecological conditions is one of the most important rangeland ecosystems in northwest of Iran due to its high biodiversity, livestock’s forage supply, soil conservation, water supply and purification, ecotourism and others (Ghorbani *et al.*, 2018). These ecosystems are widely overused by converting to agricultural, recreational, industrial and residential areas and also overgrazed extensively by rural and nomadic livestock’s (Nazari Anbaran *et al.*, 2016; Ghafari *et al.*, 2018). The results of the present study can be used to refine rangelands in this area and even to extend them to other areas. In fact, if the goal is to reduce or increase one type of PFTs, it is only necessary to make a change in soil properties that affected certain PFT. Conversely, one can cultivate plants that are adapted to the soil conditions of the region to increase production. The modeling of ANPP using factors that affects it such as the soil reduces the existing limits for measurements ANPP.

2. Unfortunately, there are few studies of soil modeling in production in Iran. In fact, we are still at the stage of how environmental factors are related to production that makes up the basic modeling information. Thus, one of the aims of this study was to investigate the relationship between the ANPP and soil properties and present a model for estimating PFTs and total of ANPP using soil properties. Moreover, we compared the accuracy of modeling based on PFTs and total ANPP.

3. In addition, rare studies have examined the relationship between soil properties and vegetation forms. Investigating a relationship between PFTs and environmental factors can predict the response of plants to environmental factors. Also, in order to protect the proper management of the rangeland, it is important to consider different responses of PFTs to environmental factors. Due to the lack of sufficient knowledge about the effect of environmental factors on the changes in total PFTs and ANPP of these rangelands, it is necessary to investigate the relationship between soil factors and ANPP. Generally, modeling ANPP was conducted based on total, but in this study, we investigate the effect of soil on PFTs.

4. As mentioned, PFTs have different type roots that allow the use of water and nutrients at different soil depths. So, it is assumed that PFTs had a relationship with soil properties at different soil depths.

5. Another aim of this study was to identify the most important soil properties that affect ANPP. Our region is arid and semi-arid and, in these areas, moisture in sandy soil is more than clay soil. So, it was assumed that soil texture was more important than other soil properties.

Material and Methods

Study area

The area under study was selected in Moghan-Sabalan region at the geographical location of 47° 45' to 48° 23' E and 38° 18' to 39° 27' N in north of Ardebil province, in northwest of Iran (Fig. 1). In terms of its socio-ecological status, the area under study can be divided into eight main utilization and ecological regions (Table 1).

Table 1. Characteristics of the study area (samples sites)

Region	Elevation (m)	Slope (%)	Precipitation (mm)	Temperature (ºC)	Dominant species
i) Moghan plain	20-150	<5	250	15.0	-
ii) Plain and hilly landscapes	150-500	2-12	259-278	15.0	*Artemisia austriaca* Jacq., *Avena eriantha* Durieu
iii) Moghan-Kalantar-Khoroslou	500-2000	9-38	278-358	8.5- 14.0	*Trifolium subterraneum* L., *Trachynia distachya* (L.) Link
iv) Arshagh	2000-1000	1-30	320-358	8.50- 9.2	*Artemisia austriaca* Jacq., *Erodium cicutarium* L'Hér.
v) Meshgin-Shahr plain	1000-1500	12-35	305-331	10.3- 12.0	*Artemisia austriaca* Jacq., *Medicago minima* (L.) L.
vi) Low mountainous areas of Sabalan Mt.	1500-2200	14-37	331-369	7.9- 10.3	*Bromus tectorum* L., *Astragalus microcephalus* Willd.
vii) Mid mountainous of Sabalan Mt.	2200-3600	19-40	369-445	3.0- 7.9	*Festuca ovina* L., *Astragalus aureus* Willd.
viii) Sabalan National Natural Monument	3600<	<40	445-510	-1.2 to 3.0	-

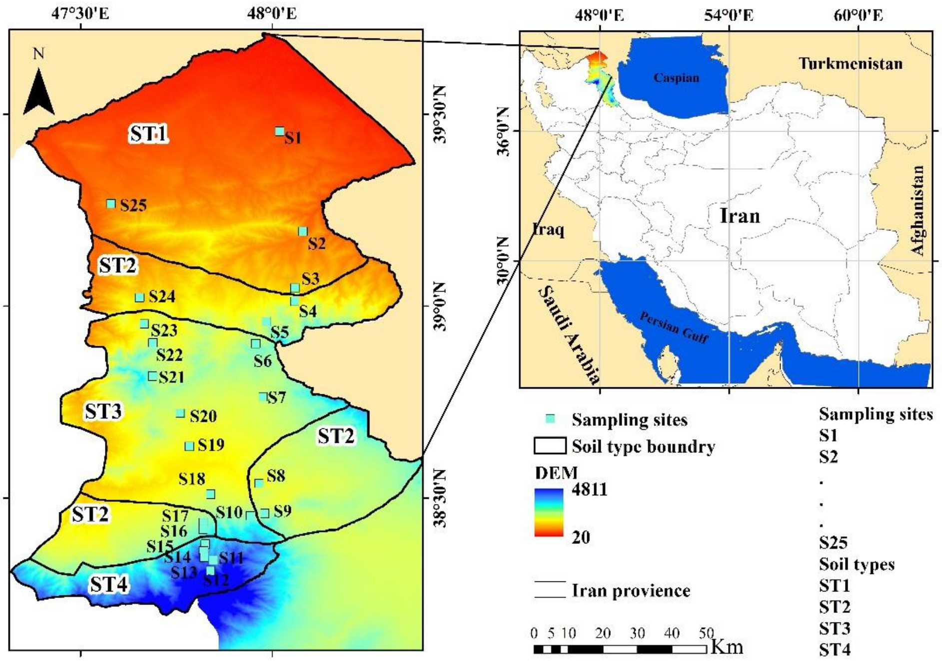

Fig. 1. Location of the study area in Ardabil province, Iran

Field data collection

According to the road accessibility, vegetation types and the purpose of the study, two elevation gradients (200 to 3300 masl) were selected and sampling was conducted. 13 and 12 habitats/sites with 300 m elevation intervals (25 sites, S1 to S25) were selected for sampling. This elevation interval was chosen because lower intervals have lower effect on the plant species variation (Wang *et al.* 2017). At each site, three parallel 100-m transects were established having 50 m distance from each other. At each transect, five 1 m^2 plots were established (15 plots for each site). The size and number of plots were determined using previous studies (Ghorbani *et al.*, 2013; Mirzaei Mossivand *et al.*, 2017) at the study area and surrounding rangelands. In each plot, the specimens pressed and sent to the Botanical Herbarium at the University of Mohaghegh Ardabili, Ardabil, Iran for identification through the support of taxonomists using literature such as Assadi *et al.* (1988-2012). Plant species were classified into three major plant functional types (PFTs) including grasses and sedges (graminoids, hereafter simply referred as "grasses"). Forbs including herbaceous annual, biennial and perennial forbs (geophytes/ cryptophytes and hemicryptophytes; hereafter simply referred to “forbs”) and shrubs (perennial chamaephytes and nanophanerophytes; hereafter simply referred as “shrubs”). From 362 identified species, 42 species (11.60%) were grasses, 302 (83.42%) were forbs and 18 (4.98%) were shrubs. Furthermore, in each plot, the ANPP values of each PFTs (forbs, grasses and shrubs) were collected by the harvesting method. Fieldwork was conducted in April to June 2016 based on the peak of the growing season. Samples were oven-dried at 75°C for 24 hours and weighed to determine mean ANPP (kg ha^{-1}) for each habitat/site. Due to the grazing livestock before sampling, especially at elevation below 2500 m based on severity of the grazing, the coefficients were applied between 10 to 30% of the estimated ANPP (Pournemati *et al.,* 2017).

In each transect, soil samples were taken from the first, middle and final plots. Sampling was carried out at two depths of 0 to 15 cm and 15 to 30 cm, which were shown respectively by D1 and D2. Soil samples were transferred to the laboratory, air dried and soil properties were measured for two soil depths. Sand, silt, clay determined by hydrometer (Elfaki *et al.*, 2016). Dispersible clay (DC) and phosphorus (P) were measured by Olsen method and spectrophotometry (Do Carmo Horta and Torrent 2007). Bulk density (BD) was defined as mass per unit volume, it is most often determined by measuring the oven-dry weight of a known sample volume (core method) (Walter *et al.*, 2016). Volumetric soil water content (VWC) and saturation percent (SP) of sample that has been dried to constant weight in oven at temperature 105ºC were measured (Page, 1992). Potential of hydrogen (pH) is measured with pH meters (Jackson, 2005). Electrical conductivity (EC) EC is measured by electrical conductivity meter (Jackson, 2005). Soil organic matter (SOM) is measured using Walkley-Black method (Roper *et al.*, 2019). Particulate organic matter (POM) is measured using dry sieving method (Cambardella and Elliott, 1992). Calcium (Ca) and magnesium (Mg) estimation of the sum of calcium plus magnesium by EDTA titration (Kimaru *et al.,* 2018), Sodium (Na), soluble potassium (SK), and exchangeable potassium (EK) extracted with ammonium acetate and analysis by flame photometry (Harris, 1995) were measured. Lime was measured by titration methods (Dunn 1943). Carbonate (CO_3^{2-}) was measured by neutralizing with acid and titration (Jackson, 2005).

Data analyses

We applied a six-stage analysis to identify the complicated relationships between the PFTs and total ANPP with soil properties.

1) The normality of data was examined using Kolmogorov-Smirnov test and log transformation was applied for non-normal variables.

2) In order to investigate the effect of soil properties on changes of PFTs and total ANPP, the study area was classified by cluster analysis. Cluster analysis (Ward linkage and Pearson distance) was used to classify sites to some groups with similar soil properties. In previous studies, several approaches have been proposed to determine the number of clusters for k-mean clustering algorithm. We used the rule of thumb method (Equation 1) that can be applied to any type of data set (Vavra and Hromada, 2017).

$$k \approx \sqrt{n/2} \qquad \text{(Equation 1)}$$

Where *n* is the number of objects (data points).

3) Soil properties, PFTs and total ANPP values were compared in each obtained soil type from cluster analysis by performing one-way ANOVA analysis (α= 0.05).

4) The multivariate statistical technique of principal components analysis (PCA) was used to reduce the number of independent variables and remove variables

that are ineffective in net primary production. In this study, 37 soil variables (19 variables related to D1 and 18 variables related to D2) were considered as independent variables. Result of correlation analysis showed that some of these variables had significant correlations with each other. Statistical analysis and model building were performed using 80% of data set and 20% was used for model verification (Mourad *et al.*, 2005).

5) Relationships between ANPP and soil properties were investigated by linear and nonlinear regression. Cluster, correlation, PCA and regression analysis was performed by Minitab.17 (Minitab Inc., Pennsylvania, USA, 2013).

6) Derived models verified root mean square error (RMSE), mean absolute relative error (MARE), mean bias error (MBE) and R (correlation coefficient) to examine the differences between predicted and measured values. MBE, RMSE and MARE are data dependent, but if their values are near zero, the predictive accuracy of the model would be higher (Elshorbagy *et al.*, 2009).

Results

Based on cluster analysis and by considering soil variables, study area was divided into four soil types (Soil type 1: ST1, soil type 2: ST2, soil type 3: ST3 and soil type 4: ST4) (Fig. 2). Sites in ST1 and ST4 are located respectively in plain Moghan and Sabalan Mountain, ST2 and ST3 were located in Khorosloo Kalantar. Sites in each soil type had alike properties of soil for growing plants. Among 37 soil variables, there were significant differences between four soil types for 26 variables ($P<0.01$ and $P<0.05$) (Table 2). Results showed that there was a significant difference between habitats in low versus high altitudes. Mean values of forbs, grasses, shrubs and total ANPP have significant differences between four soil types ($P<0.05$). In fact, it was concluded that changes in ANPP were related to changes in soil variables. Because of changing in soil variables, the value of ANPP for each PFTs has also changed.

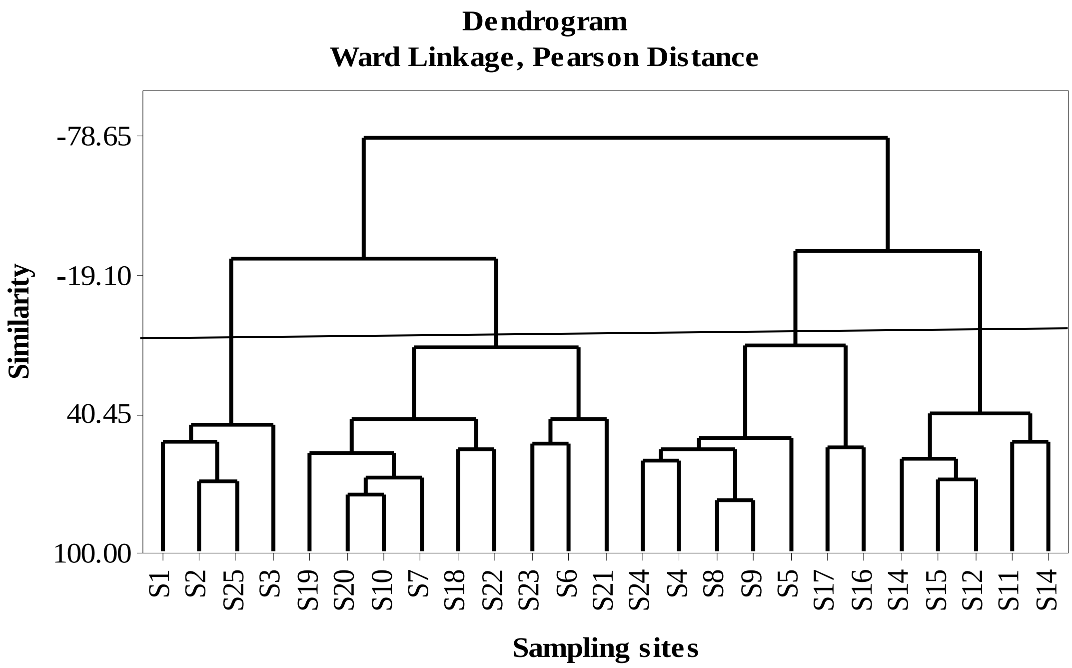

Fig. 2. Diagram of cluster analysis for soil properties

Information of the four soil types based on cluster analysis was as follows:

ST1, this soil type includes S1, S2, S3 and S25 sites, which were the part of winter rangelands at low altitudes. They had higher values of forbs ANPP (674.7 kg ha^{-1}) (Fig. 3). EC had the lowest value at two depths of soil compared to other groups. While the percent of clay D1 and clay D2 were more than other soil types. However, sand and organic matter has the lowest value in D1 and D2 in this soil type. Soil texture was clay to silty clay loam.

ST2, this soil type includes S4, S5, S8, S9, S16, S17 and S24 sites, which are the part of mid altitude rangelands. This soil type had the lowest forbs, grasses and shrubs ANPP compared to the other soil types and soil variables were between ST1 and ST4. The characteristic of this soil type is the lowest value of reproducing P D2. Moreover, the most value of silt D1, pH D2 and Mg D2 belongs to this soil type. Soil texture is clay loam to sandy loam.

ST3, this soil type includes S6, S7, S10, S18, S19 to S23 sites, which are the part of mid altitude rangelands either. Maximum and minimum values of ANPP are respectively for forbs and shrubs PFTs at these sites. This soil type has the lowest EC D1 and D2, EK D1 and D2, Na D1, POM D1 and D2 among the four soil types. Soil texture was sandy loam to clay loam.

ST4, this soil type includes S11 to S15, which were the part of summer rangelands at high altitudes. This soil type had the most value of, grasses, shrubs and total ANPP among the four soil types. pH D1, D2 and clay D1 and D2 had minimum values in this soil type. While the most value of EC D1 and D2 is in this soil type. The maximum sand D1, sand D2, SOM D1, SOM D2 were in this soil type. Soil texture was sandy loam.

Table 2. Means comparison of soil variables in different soil types obtained from cluster analysis

Soil variables	ST1	ST2	ST3	ST4	F	P-value
Sand D1 (%)	20.87^{c}	43.23^{b}	57.75^{ab}	61.67^{a}	13.10	0.00^{**}
Sand D2	18.71^{c}	40.08^{b}	58.93^{a}	59.74^{a}	19.88	0.00^{**}
Silt D1 (%)	31.95^{a}	32.32^{a}	22.98^{b}	24.45^{b}	3.33	0.03^{*}
Silt D2	30.43^{a}	30.05^{a}	22.10^{b}	26.35^{ab}	4.53	0.01^{**}
Clay D1 (%)	47.18^{a}	24.45^{b}	19.27^{b}	13.88^{b}	12.87	0.00^{**}
Clay D2	50.86^{a}	29.86^{b}	18.97^{bc}	13.91^{c}	17.75	0.00^{**}
DC D1 (%)	63.79^{a}	15.95^{b}	32.77^{b}	25.70^{b}	13.52	0.00^{**}
DC D2	64.60^{a}	20.59^{b}	33.21^{b}	32.34^{b}	8.41	0.00^{**}
BD D1 (gr/cm^3)	1.28^{a}	1.18^{ab}	1.22^{a}	1.02^{b}	5.60	0.00^{**}
VWC D1 (%)	0.04	0.05	0.04	0.05	0.51	0.60^{ns}
VWC2	0.04	0.05	0.04	0.04	0.64	0.60^{ns}
SP D1 (%)	69.02^{ab}	54.27^{b}	53.53^{b}	69.26^{a}	5.10	0.00^{**}
SP D2	60.00	53.74	42.28	59.44	1.87	0.16^{ns}
pH D1	7.30^{a}	7.37^{a}	7.06^{a}	6.15^{b}	12.67	0.00^{**}
pH D2	7.30^{a}	7.48^{a}	7.34^{a}	6.47^{b}	12.24	0.00^{**}
EC D1 (μS/cm)	657.10^{b}	844.00^{ab}	657.00^{b}	1188^{a}	3.13	0.04^{*}
EC D2	386.30^{b}	581.40^{a}	387.60^{b}	612.50^{a}	7.82	0.00^{**}
SOM D1 (%)	5.74^{b}	8.18^{b}	6.34^{b}	12.77^{a}	11.67	0.00^{**}
SOM D2	3.54^{b}	6.05^{b}	4.65^{b}	10.18^{a}	13.14	0.00^{**}
POM D1 (%)	3.25^{a}	2.88^{a}	0.65^{ab}	1.74^{ab}	8.00	0.00^{**}
POM D2	1.55^{ab}	1.78^{a}	0.63^{b}	1.04^{ab}	5.21	0.00^{**}
Ca D1 (ppm)	10.68	7.61	6.03	5.36	2.67	0.07^{ns}
Ca D2	3.20^{b}	4.46^{a}	3.39^{b}	4.49^{a}	7.37	0.00^{**}
Mg D1 (meq/l)	4.00	4.70	4.11	6.01	1.83	0.17^{ns}
Mg D2	3.75	4.87	3.96	3.73	3.11	0.05^{ns}
P D1 (ppm)	100.00	27.05	213.00	103.40	1.11	0.36^{ns}
P D2	60.90	27.12	114.1	90.8	0.61	0.61^{ns}
Na D1 (meq/l)	0.76^{bc}	1.67^{ab}	0.67^{c}	2.06^{a}	9.02	0.00^{**}
Na D2	0.90	1.70	1.02	1.51	2.68	0.07^{ns}
SK D1 (ppm)	25.26	24.83	25.06	40.21	1.20	0.30^{ns}
SK D2	20.69	12.36	16.92	24.94	2.21	0.11^{ns}
EK D1 (ppm)	820.00^{a}	595.10^{ab}	417.50^{b}	486.70^{b}	4.74	0.01^{**}
EK D2	715.10^{a}	509.60^{ab}	377.40^{b}	422.50^{ab}	3.40	0.03^{*}

Lime D1 (%)	8.27[a]	5.96[a]	2.57[b]	1.35[b]	9.45	0.00**
Lime D2	8.16[a]	7.91[a]	2.93[b]	1.53[b]	12.15	0.00**
CO_3^{2-} D1 (meq/l)	5.51[a]	3.71[b]	2.91[b]	2.74[b]	7.91	0.00**
CO_3^{2-} D2	4.31[a]	4.03[a]	2.90[b]	2.58[b]	10.20	0.00**

D1 (0-15 cm soil depth), D2 (15-30 cm soil depth). Different letters in each row shows significant differences. ** P<0.01, * P<0.05, ns is no significant

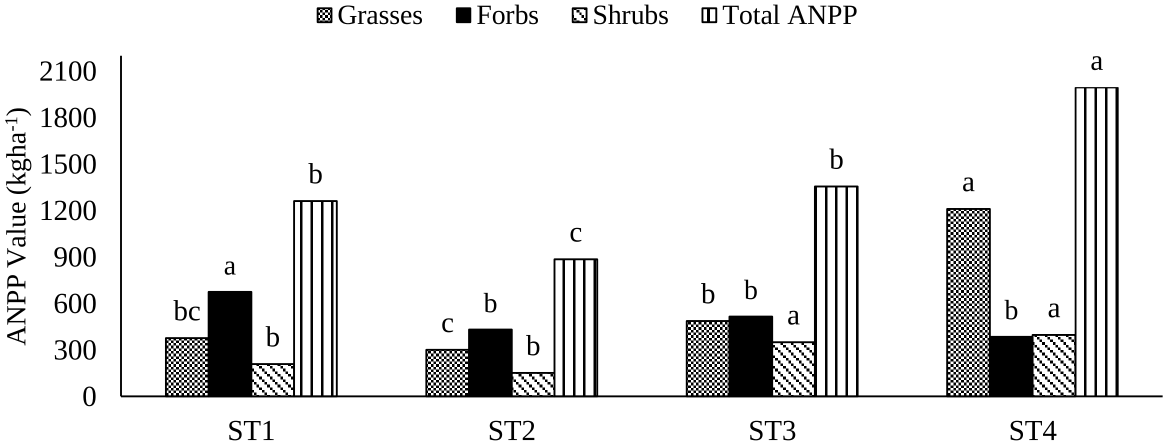

Fig. 3. Mean Comparison of each plant functional types and total ANPP value between soil types

Principal component analysis

The results of correlation analysis showed that there was a significant correlation between soil variables. The first five components accounted for 79% of soil variation among different sites (Tables 3 and 4). The first component (PC1) had the highest correlation with the amount of sand and clay and accounted for 30% of soil variation. The second PC reflects more soil moisture (VWC D1 and D2). The three to five axis reflects soil nutrient properties (Mg D2, POM D2, P D2 and SK D2). Finally, based on PCA, the important soil variables were selected.

Table 3. Cumulative variance and eigenvalues for the first five principal component (PC) axes

Component	PC1	PC2	PC3	PC4	PC5
Eigenvalues	12.88	7.03	4.48	2.93	2.68
Variance (%)	35.30	18.00	11.50	7.60	6.90
Cumulative variance (%)	35.30	53.40	64.90	72.50	79.40

Table 4. Eigenvectors for the first five principal components (PC) axes

Variable	PC1	PC2	PC3	PC4	PC5
Sand D1	**-0.94**	-0.19	-0.19	0.02	0.08
Sand D2	**-0.91**	-0.27	-0.23	-0.02	0.00
Clay D2	**0.90**	0.25	0.15	-0.00	0.07
Clay D1	**0.86**	0.39	-0.06	-0.17	-0.03
Lime D1	**0.80**	0.02	0.42	0.23	0.04
pH D1	**0.76**	-0.54	0.13	-0.08	0.18
Lime D2	**0.72**	-0.17	0.48	0.21	0.30
POM D1	**-0.70**	0.51	0.28	-0.16	0.13
SOM D2	**-0.72**	0.39	0.28	-0.20	-0.04
VWC D1	-0.06	**0.93**	-0.10	-0.16	-0.00
SK D1	-0.48	**0.70**	-0.00	0.34	-0.05
VWC D2	0.07	**0.69**	0.08	-0.40	-0.02
P D1	0.09	**0.64**	-0.48	-0.12	0.46
EK D2	0.65	**0.65**	0.15	0.20	-0.12
Mg D2	0.00	-0.13	**0.71**	-0.14	-0.11
SP D1	0.00	0.06	**0.56**	-0.75	0.10
Silt D1	0.47	-0.30	**0.55**	0.28	-0.13
POM2	0.37	0.40	**0.51**	-0.05	0.51
SP D2	0.03	0.11	0.38	**-0.80**	0.06
Na D2	-0.33	-0.05	0.03	0.25	**0.64**

D1 (0-15 cm soil depth), D2 (15-30 cm soil depth)

Regression Analysis

Based on regression analysis, clay, POM, VWC and Mg in D2 were effective in shrubs ANPP (Table 5). The relationship between shrubs ANPP with clay and Mg in D2 was negative, but with the amount of SP and POM in D2 was positive, which by increasing the value of POM and VWC in D2, the value of ANPP was increased. The K and P in D1 were effective on the grasses ANPP. By increasing K and P in D1, the grasses ANPP had increased. Forbs ANPP were related to VWC and P in topsoil and EK and Mg in the subsoil. By increasing VWC, P and Mg, forbs ANPP was decreased. However, the relationship between EK and forbs ANPP was positively significant and with increasing EK, forbs ANPP were increased. Total ANPP was related to pH in topsoil and sand and POM in subsoil. By increasing pH, forbs ANPP were decreased. But the relationship between sand, POM and total ANPP was positively significant and by increasing sand and POM, total ANPP was increased. According to Table 6, models for grasses and total ANPP respectively estimate ANPP with 150 kg ha^{-1} less and 100 kg ha^{-1} more against measured ANPP. Though selected models for shrubs and grasses ANPP estimates with an error of about 50 kg ha^{-1}.

Table 5. Selected model for PFTs and total ANPP

Model	R^2	P-value
$Y_{Grasses}$ = 2.10+ 0.02 SK D1 + 0.001 P D1	0.51	0.00
Y_{Forbs} = 1182.00 -7676.00 VWC D1 – 0.56 P D1 + 0.70 EK D2 -135.50 Mg D2	0.61	0.00
Y_{Shrubs} = 3.32 – 0.07 Clay D2 + 15.31 VWC D2 – 0.35 Mg D2 +0.63 POM D2	0.71	0.00
Y_{Total} ANPP = 3492.00 – 556.00 pH D1+31.19 Sand D2 +235.00 POM D2	0.76	0.06

D1 (0-15 cm soil depth), D2 (15-30 cm soil depth)

Table 6. Verifying selected models by using evaluation statistics and unused data in modeling

Dependant var.	Measured ANPP (kg ha^{-1})	Predicted ANPP (kg ha^{-1})	MBE	RMSE	MARE	R^2
$Y_{Grasses}$	614.99	765.46	205.38	126.44	1.49	0.11
Y_{Forbs}	519.16	467.13	47.51	325.87	0.76	20.60
Y_{Shrubs}	275.92	316.71	174.88	293.04	0.94	13.10
Y_{Total}	1410.08	1299.50	197.34	755.51	0.54	29.10

RMSE=Root mean square error, MARE=Mean absolute relative error, MBE= mean bias error and R^2= Coefficient of determination

Discussion

The result of this study showed that soil variables were effective on ANPP such that values of ANPP between sites were changed by different soil variables. In addition, soil variables affecting primary net production were different for each vegetative form. Cluster analysis showed a clear distinction between plain Moghan (ST1), Khorosloo Kalantar (ST2 and ST3) and Sabalan Mountain (ST4) rangeland concerning their soil properties. ANPP of life forms was also different between the four soil types. Our study illustrates the strong correlations among soil factors and ANPP (Tateno and Takeda, 2003; Griffiths *et al.,* 2009; Finzi *et al.,* 2014). So, it is possible to estimate ANPP using soil factors. Other studies have also used soil properties to estimate ANPP, for example in light use efficiency models, which has been used to estimate ANPP at various spatial and temporal scales (Yuan *et al.,* 2007), vegetation ecosystem modeling and analysis project (VEMAP) (Jager *et al.,* 2000) and vegetation production model (VPM) (Yuan *et al.,* 2007). One of the input parameters in model is soil properties. The results demonstrate that soil properties were effective on ANPP, but different soil variables have different impacts on the different functional group. The relationship between the soil properties with the various functional groups is strong in some cases although it is moderate or weak in some.

According to the regression models, the shrubs ANPP is related to the soil characteristics in the D2. This is due to the root system of the Shrubs. Shrubs have deep roots that can absorb moisture from the depths of soil, especially during the drought when the surface layer of the soil has lost its moisture content (Sharifi *et al.,* 2018). Based on regression models, clay is effective on Shrubs ANPP. Soil texture is effective in ANPP by affecting the amount of moisture and nutrient availability to the plants, Soil water holding capacity, nutrient cycle, ventilation, and depth of penetration of the root (Easton and Bock, 2016). Thus, when clay increased, mechanical resistance to root penetration has increased and as a result, decreases ANPP (Bengough and Mullins, 1997). Soil clay, when wet and grazed by livestock compactible more than sand soil and compaction can reduce plant growth (Drewry *et al.,* 2008), so with increase clay, shrubs ANPP has decreased.

In the Sabalan region, sand is more than the Moghan area. Also, the amount of organic matter in the Sabalan area is higher due to its more vegetation, which can improve soil water holding capacity (Hossein Jafari *et al.*, 2019) in the Sabalan region and increase shrubs ANPP. Also, with increasing VWC, shrubs ANPP decrease. The high VWC causes the soil to retain more moisture and increase plant growth by increasing soil moisture storage. The VWC is a function of soil texture, soil porosity and organic matter (Ren *et al.,* 2015). For example, shrubs ANPP in ST2 group was less than ST4 because grazing in ST2 is more than ST4. Thus, in the regions with a light grazing, the amount of organic matter is higher and soil can save more water. However, in areas with heavy grazing, the soil water holding capacity decreases due to livestock trampling and as well as the reduction of organic matter content. While Mg is a macro element for increasing ANPP of rangeland (Mugerwa *et al.,* 2008), but based on regression model, with the increased Mg, shrubs ANPP decrease. This can be due to the complex interactions among its biological, chemical and physical soil properties (Villalobos and Fereres, 2016).

High levels of Ca and Ek are associated with Mg absorption by the vegetation. As a result, reducing Mg may affect values of Ca and Ek that is available for vegetation, physical and chemical properties of soil and the growth of the vegetation (Schilling and Lockaby, 2006). By increasing the POM, the ANPP increases. It is the most easily decomposable fraction of non-living SOM after microbial biomass, POM fulfills many soil functions mediated by OM. POM enhances aggregation stability, water infiltration and soil aeration; it increases cation exchange capacity and buffering pH. Soil organic matter due to the reduced soil bulk density increases soil permeability to air and water and increases root penetration in the soil, maintaining water and nutrients in the soil with effects on optimizing vegetation growth. Also, it is a source of nutrients /energy for plant growth (Handayani *et al.,* 2010).

Grasses ANPP was related to the P in D1. P is one of essential elements and also one of the most important macronutrients for plant life. A positive correlation was detected between SOM and P in the superficial soil horizons (Fink *et al.,* 2016). Therefore, soils with higher levels of P are rich in SOM and grasses ANPP is high in them. Read *et al.* (2007) reported forage of Bermuda grasses and Annual Ryegrasses-Bermuda grasses increased with increasing P content. Silvertown *et al.* (2006) and Ward *et al.* (2017) reported that Nitrogen and P fertilization had additive effects on ANPP and addition of N and P to African grassland led to the highest yield. Comparison of the amount of P in ST1 (Moghan sites) and ST2 (Sabalan sites) shows that the amount of P equalled in both regions, but the amount of grasses ANPP in Moghan was less than Sabalan. It can be said that the reason for the increase of P in the Moghan region is due to severe grazing.

Grazing livestock increases Amount and displacement of livestock waste and the greater burial of litter and the increase of phosphorus in the soil surface (Mashkori *et al.,* 2017). So, although P is high, the grasses ANPP is reduced. By increasing the SK in D1, the amount of grasses ANPP increased. Because K is one of the most important nutrients in the soil that was effective in plant growth, Soil fertility (Schjoerring *et al.,* 2019) reduces evapotranspiration, increasing plant resistance to drought. In sites of ST1, the amount of SK was less than that of ST4 (Sabalan); as a result, the ANPP grasses in Moghan were less than Sabalan. Reducing SK in D1 in Moghan can be due to the loss of nutrients through erosion and the reduction of organic matter due to rainfall (Huffmanet *et al.,* 2001).

The function of forbs was unlike grasses and shrubs from Moghan to Sabalan, the shrubs and grasses ANPP was increased while forbs ANPP decreased and relationships between forbs ANPP and P in D1, Mg in D2 and VWC in D1 were negative. It can be said that the forbs ANPP was influenced by another factor such as livestock grazing or temperature more than VWC although the moisture content in ST1 and ST4 sits were the same, the forbs ANPP had significantly changed. Forbs as a class of range plants were often looked upon with disfavor when they occur on rangelands. There is a good reason for this unfavorable view of forbs. Many forbs are opportunistic and do invade disturbed areas. If vigor of grasses is lowered by heavy grazing, forbs often increased. Because of this phenomenon, many range managers consider ranges with abundant forbs to be deteriorated. Some of these forbs may be poisonous and can create additional problems for livestock operators (Pieper and Beck, 1980). In present study, forbs with low preference value in ST1 site was more than ST2. Also, in the high elevation, meadows were often considered to be primarily temperature-limited. Also, growing season length and soil moisture availability both limit primary production. Increases in growing season length can increase ANPP unless those increases are accompanied by soil moisture availability decreases (Jafarzadeh *et al.,* 2019). Although VWC is high, the decline in the temperature and growing season can reduce forbs net primary production. Although Ca and Mg become important nutrients required for the increased rangeland production and using cattle manure on the degraded rangelands significantly increased pasture biomass yield properties. However, forbs ANPP decrease with the increase of Mg in D2. The reason for this is that the soil properties affect each other. For example, Mg uptake by plant roots is dependent on several factors including the amount of Mg in solution, soil pH, percent Mg saturation of the CEC, and clay type (Schilling and Lockaby, 2006).

The relationship between total ANPP and pH in D1 was negative. Soil pH influences nutrient levels as well because many macro- and micro-nutrients are most accessible by plants within specific pH ranges (Collins and Foster 2008), this result is consistent with the results of other studies in this issue. For example, Dunn *et al.* (2008) showed pH is effective on vegetation composition due to the reduced access to nutrients in the soil, especially in low-altitude rangelands in South China that have been degraded. But Ward *et al.* (2017) found no significant effect of pH on total ANPP, but there was a significant interaction effect between pH and ANPP of five common species including *Themeda triandra, Tristachya leucothrix, Setaria sphacelata, Eragrostis curvula,* and *Panicum maximum.* Results show that POM in D2 had a positive effect on total ANPP. POM was considered an intermediate available fraction of organic C and N and more sensitive to the land management changes compared to total soil organic matter (Handayani *et al.,* 2010). POM improves plant growth due to increasing the ability of the soil to store and transport the water and air and supplies the nutrients needed for the plant (Franzluebbers *et al.*, 2000). Also, sand in D2 had a positive effect on total ANPP. Collins and Foster (2008) showed that areas with more net primary production are located at low altitude and their pH is low and soil is composed of more silt and sand particles than region with low NPP. Dodd and Lauenroth (1997) showed that sandy clay loam and sandy clay soils on average had greater water availability in layers 30 cm and above, but the loamy sand had the greatest water availability in layers beneath this, particularly at 105 cm. This observation can be linked to the occurrence of fine textured subsoil at this site. The textural pattern in the loamy sand profile effectively creates two water resources: a shallow pool accessible to all plants; and a deep pool accessible only to deep-rooted plants. ANPP data for the three sites along with transpiration estimates from the model simulations indicated that the additional water availability in the coarser textured soil was associated with higher overall plant productivity.

Conclusion

The results showed that the different soil properties are required for estimating each PFTs ANPP. So, it is possible to achieve the proper ratio of PFTs by changing the physical and chemical soil properties. The results also showed that soil depth is one of the factors affecting ANPP estimation and different PFTs are related to soil properties at different depths of soil due to their root extension depth. In arid and semi-arid regions, ANPP in coarse-grained soils is more than fine-grained soils due to the reduced evaporation. So, in our study, sandy soil increased with the increase of elevation so that ANPP in high elevation is more than low elevation. Based on the result, PFTs can be a suitable indicator for soil condition of rangeland. So, the results of the present study can be used to rangeland and improvement in this area and even to extend them to other areas. In this study, there was a significant relationship between soil properties and ANPP. According to the obtained models, ANPP changes can be predicted by soil variables. While in order to get more accurate models, it is necessary to examine the effect of other parameters on ANPP such as topography and climate. But the results of the present study showed that soil properties alone probably represent a high percentage of changes in primary net production.

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چکیده. هدف از این تحقیق بررسی رابطه بین تولید خالص اولیه کل و فرم‌های رویشی با ویژگی‌های خاک است. نمونه‌برداری در گرادیان ارتفاعی ۲۰ تا ۳۳۰۰ متر و ۲۵ سایت در مراتع شمال استان اردبیل در سال ۱۳۹۵ انجام شد. در هر سایت تولید خالص اولیه سطح زمین کل و فرم‌های رویشی و خاک نمونه‌برداری شد. در آزمایشگاه ویژگی‌های خاک شامل شن، رس، سیلت، رس قابل انتشار، وزن مخصوص ظاهری، محتوای رطوبتی خاک، درصد اشباع، اسیدیته، هدایت الکتریکی، ماده آلی، ماده آلی ذره‌ای، کلسیم، منیزیم، فسفر، سدیم، سدیم تبادلی، سدیم محلول، آهک و کربنات اندازه‌گیری شد. در ابتدا سایت‌ها با استفاده از آنالیز خوشه‌ای بر اساس ویژگی‌های خاک دسته‌بندی شدند. برای مقایسه مقدار تولید خالص اولیه سطح زمین و ویژگی‌های خاک در گروه‌های حاصل از آنالیز خوشه‌ای، از آنالیز واریانس و آزمون توکی استفاده شد. سپس برای بررسی رابطه تولید خالص اولیه سطح زمین و ویژگی‌های خاک از آنالیز رگرسیون استفاده شد. بر اساس آنالیز خوشه‌ای سایت‌های مورد مطالعه در چهار گروه تقسیم شدند و نتایج نشان داد که مقدار تولید خالص اولیه کل و هریک از فرم‌های رویشی و ۲۶ ویژگی خاک از میان ۳۷ ویژگی مورد بررسی دارای تفاوت معنی‌دار بین گروه های خاک هستند. مدل رگرسیونی نشان داد که پتاسیم محلول و فسفر در عمق اول بر روی گراس (R^2=۰/۵۱)، محتوای رطوبتی خاک و فسفر در عمق اول و پتاسیم تبادلی و منیزیم در عمق دوم بر روی پهن‌برگ (R^2=۰/۶۱) و رس، محتوای رطوبتی خاک، منیزیم و ماده آلی ذره‌ای در عمق دوم بر روی بوته‌ای‌ها (R^2=۰/۷۱) و اسیدیته در عمق اول، شن و ماده آلی ذره‌ای در عمق دوم بر روی تولید خالص اولیه کل (R^2=۰/۷۶) موثر بودند. برطبق مدل‌های به‌دست آمده، امکان پیش‌بینی تغییرات تولید خالص اولیه سطح زمین با استفاده از متغیرهای خاک وجود دارد. براساس نتایج گروه‌های عملکردی می‌توانند شاخص مناسبی از وضعیت خاک مرتع باشند. بنابراین نتایج این تحقیق می‌تواند برای اصلاح و مدیریت مراتع این منطقه و حتی تعمیم به مناطق دیگر مورد استفاده قرار گیرد.

کلمات کلیدی: گروه‌های عملکردی، پهن‌برگان، گندمیان، بوته‌ها، خصوصیات خاک