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**EFFECT OF LAND USE AND TOPOGRAPHY ON SOIL
PROPERTIES AND AGRONOMIC PRODUCTIVITY ON
CALCAREOUS SOILS OF A SEMIARID REGION, IRAN**

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EFFECT OF LAND USE AND TOPOGRAPHY ON SOIL PROPERTIES AND AGRONOMIC PRODUCTIVITY ON CALCAREOUS SOILS OF A SEMIARID REGION, IRAN

Abstract

In this research the effects of land use and slope position on soil properties and its agronomic productivity were studied in a greenhouse experiment. The study also covered the effects of water stress, fertilizer treatment and their interactions. Eight soil samples were collected from four slope positions along hillslopes from two adjacent land use types of rangeland and dry farmland in a semi arid region of Iran. Soil samples were analyzed for their physical and chemical properties and yield and yield components of wheat were measured as indices of soil agronomic productivity in a replicated pot experiment. Soils of the dry farmland showed higher fertility and better quality than the soils from the adjacent degraded rangeland, especially at the upper slope positions. The results indicated that yield components of wheat were all higher in the dry farming land compare to the degraded rangeland, and in the bottom of slopes compared to the top. The effect of land use and slope position on agronomic productivity of soil was influenced by water supply. The actual impact on soil productivity of soil degradation, induced by land use and slope position, was overshadowed by the dominating effect of water stress. While both chemical fertilizer and fertilizer+manure treatments enhanced the agronomic productivity of all soils, their effects were much more pronounced on the degraded soils of the rangeland. Water stress reduced fertilizer efficiency on all the soils used in this study.

KEY WORDS: dry farming; rangeland; slope position; fertilizer; water stress

INTRODUCTION

The sustainable use of soils is essential for overcoming global issues of 21st century like food security, energy and water shortage, climate change and biodiversity (Lal, 2009; Jones *et al.*, 2009). Soil erosion has been recognized as a major form of soil degradation which adversely affects soil quality by reducing infiltration rates, water-holding capacities, nutrients, organic matter, soil biota and soil depth (Pimentel *et al.*, 1995). Soil erosion also causes a reduction of soil productivity (Verity and Anderson, 1990) and a significant ecological damage by depleting soil biodiversity and affecting plant composition (Lal and Fierce, 1991). Global climate change is expected to exacerbate these problems through changes in atmospheric conditions and land-use.

Soil translocation by tillage and water erosion induces changes in the physical and chemical properties of the soil, including changes in soil texture, organic matter content, chemical composition, nutrient concentrations, and bulk density (Kosmas *et al.*, 2001; de Alba *et al.*, 2004). Removal of soil from up slopes can result in the exposure of subsoil material at shoulder positions and soil deposition patterns may result in a deep A horizon in depressions (Kosmas *et al.*, 2001) or a buried A horizon under some conditions (de Alba *et al.*, 2004).

The spatial variability in quality and quantity of crop yields is often related to the spatial variability in soil quality indicators. In some cases, the spatial variation in soil properties affecting plant growth has been directly linked to changes induced by soil translocation through tillage (Kosmas *et al.*, 2001). Within-field variability in parameters including soil depth, available soil water, nutrients, pH, organic matter content, and indicators of clay content (electrical conductivity and cation exchange capacity) have been reported to affect yield (Kosmas *et al.*, 2001) and crop quality

(Stewart *et al.*, 2002). Many studies have indicated that grain yields are depressed in areas of a field susceptible to low soil moisture, especially those with coarse soil texture and low organic matter contents. Yields tend to be lowest in eroded areas where calcareous subsoil is exposed and highest in concave positions, which have relatively deep topsoil, especially in dry years (Stewart *et al.*, 2002).

Differences in soil forming factors and processes along a hillslope result in significant differences in soil properties (Brubaker *et al.*, 1993) and plant production (Jones *et al.*, 1989). Soil properties and vegetation can also be altered over time under different land uses, management systems and soil erosion along a hillslope. In rangelands, grazing and more particularly overgrazing and its attendant effect of depletion of plant cover and litter and trampling of the soil is the most important factor contributing to erosion (Branson *et al.*, 1981).

Rangelands, generally located on steep slopes of semi-arid zones, are prone to severe soil erosion. Continued overgrazing or uncontrolled grazing always reduces plant cover that protects the soil and generally results in soil erosion and compaction. Soil erosion, which is a serious problem in many countries, is 20-30 times more than the tolerance in Iran (Jalalian *et al.*, 1996).

The demand for a standardized methodology for assessing and collecting information on the productivity function of soils has been emphasized by Mueller *et al.* (2010). This study was aimed to evaluate changes in productivity and soil properties along a landscape on a coupled degraded range land and a dry farming land in a calcareous soil. Yield and yield components of wheat were determined as soil productivity indices as influenced by fertilizer application and water stress.

MATERIALS AND METHODS

Soil Sampling and Analysis

Soil samples were taken from a topographically complex landscape (33° 30' 12" N, 47° 12' 18" E, altitude: 1100 m) in Lorestan province, Iran (Figure 1a), with mean annual temperature of 15.8°C, mean annual precipitation of 376 mm, and potential evapotranspiration of 1835 mm. Samples (four pairs) from 0-20 cm depth were randomly collected from up, middle upward, middle downward and foot slope of the hillslope (Figure 1b). The average slope steepness was 17, 26, 20 and 10 percent for the slope positions from up to down, respectively. Each pair of the samples consists of one sample from dry farming field and the other from adjacent rangeland in the same slope position. Soil samples were obtained on early August. The cultivation was conventional up-down tillage by plow tillage (moldboard plow) for about 20 years during that the farmer used to apply annually manure and N-P-K fertilizers. On the other hand, the adjacent permanent rangeland was a degraded rangeland (vegetation cover less than 20%) due to intense grazing and dry climate condition.

Based on four slope positions and two land uses (dry farming and range), eight composite soil samples were collected for the greenhouse experiment. Each composite sample weighted about 100 kg and taken from a 2×4 m rectangular. Also eight (disturbed and undisturbed by cylinder) soil samples with two replications were randomly collected for the chemical and physical analysis. The chemical and physical analysis carried out on air dried <2 mm samples. Measured properties were, soil texture, pH, electrical conductivity (EC), total nitrogen (N), available phosphorous (P) and potassium (K), organic matter content (OM), field capacity moisture (FC), calcium carbonate equivalent (CCE), cation exchange capacity (CEC), bulk density (Bd) and

mean weight diameter (MWD) of soil aggregates. The soil properties were determined by methods described by Klute (1986) and Sparks (1996).

Greenhouse Evaluation of Soil Productivity

A factorial experiment based on completely randomized design with three replications was used in the greenhouse experiment to compare the effect of four factors on yield and yield component of wheat. The factors were land use (dry farming and range lands), slope position (up, middle upward, middle downward and foot slope), water stress (with and without water stress) and fertilizer (non-fertilization, chemical fertilization and chemical fertilization+manure). Urea (130 kg ha^{-1}), super phosphate triple (150 kg ha^{-1}) and potassium sulfate (250 kg ha^{-1}) were used in the chemical fertilization pots. Sheep manure (equivalent to 20 ton ha^{-1}), Urea (60 kg ha^{-1}), super phosphate triple (125 kg ha^{-1}) and sulfate potassium (20 kg ha^{-1}) were used in the chemical+manure fertilization pots. Urea was splitted and used in three stages. Water stress applied from the beginning of earing (end of shooting stage) to the end of growth period by doubling the length of time between two consecutive irrigations as compared to no water stress treatment in which irrigation was done in the depletion limit of 50 ± 5 percent of available water content by weighing the pots. Plants in the pots with limited irrigation showed signs of water stress.

A spring wheat (*Triticum aestivum* L. cv. Atrak) planted with the density of four plants per pot. At the end of growth period, dry matter, grain yield, grain number and grain weight were determined. The obtained data were analyzed by glm procedure of SAS (Statistical Analysis System, 1996) software and Tukey's test was used to compare the mean values.

RESULTS AND DISCUSSION

Soil Properties

Table I summarizes some of the general properties of the soil samples used in this study. Soil texture varied from clay loam (CL) to silt loam (SiL), but the variations were random with no significant difference between treatments. The same was true for texture related properties such as Bd, FC and pH. However, land use, slope position, and the interaction between the two had significant effects ($P \leq 0.01$) on total N, available P and K, OM, gravel (particles >2 mm) content, Calcium Carbonate Equivalent (CCE), and CEC. Mean weight diameter (MWD) of soil aggregates was significantly ($P \leq 0.01$) affected by slope position but not by land use type.

The interactive effect of land use and slope position on soil properties are summarized in Figure 2. The soil OM was generally higher in the dry farming land than the adjacent rangeland, with the differences being higher in the upper parts of the slope than in the footslope. The middle slope section of the landscape on both land use types, where the slope steepness was at its highest, had the lowest level of OM of the three locations (Figure 2). These differences may be due to (i) soil and OM translocation through tillage and erosion from upper to lower part of the slope, (ii) the annual application of manure in the dry farmland, and (iii) over-grazing of the rangeland. Total N also showed similar variation with land use type and slope position. While there was no significant difference between two land use types in the footslope, total N was significantly lower in the rangeland than the dry farming land on the upper slopes (Figure 2). This similarity in the pattern of change in N and OM is expected as total N is mostly consists of organic N. Similar results have been reported by other researchers

(e.g. Raiesi, 2007; Hajabasi and Falahzadeh, 2009) for central Iran, where most rangelands are severely overgrazed and degraded.

Available K and P showed a similar trend between treatments (Figure 2). While there was a significant difference between farmland and degraded rangeland at the lower slopes, no significant difference was observed at the upper slopes. These results show that dryland farming on steep slopes reduces soil quality and increases soil degradation, even under good agricultural practices such as fertilizer and manure application. Available soil P was shown by Hajabassi *et al.* (2002) to be higher in the top 10 cm of dry farmlands than the adjacent degraded rangelands in the semiarid region of Iran.

The effect of slope positions on P and K was generally higher in the farmland than in the rangeland, which indicates a possible mass downslope transport of top soil by tillage practices and erosion. Da Silva and Alexandre (2004) and Lobo *et al.* (2005) also reported higher concentrations of N, P and K at the bottom of slopes due to erosion.

The farmland soils had higher CEC values than the rangeland soils at all slope positions, but the differences were lower at the upper than the bottom slopes (Figure 2). These differences follow that of the clay and OM of the two land use types and slope positions. This is in agreement with the results obtained by Caravaca *et al.* (1999).

The changes in CCE of the soils from different land use types and slope locations were in reverse order to those properties discussed above (Figure 2f). Because of more than 20 years of tillage and cultivation practices, it was expected that calcium carbonates leaching to be more pronounced in the farmlands and on higher slopes. The higher levels of CCE in the surface soils of upper slopes, therefore, indicates the loss of top soil by erosion and the exposure of calcareous subsoil material (Papiernik *et al.*,

2005) at the upper slope positions. Mehdizadeh *et al.* (2010) also found that CCE is higher at the upslope than mid and foot slope.

Figure 2g shows that while percent gravel is uniform across the landscape in the rangeland, it is higher at the upper than the lower slopes in the farmland. MWD of soil aggregates also increased from the top to the bottom of slope (Figure 2h) but the difference between the two land use types was insignificant. The expected positive impact of higher OM and clay content of farmland on MWD appears to have been cancelled out or overshadowed by the negative effect of tillage practices (Mc Vay *et al.*, 2006). Soil EC was higher at the footslope than on the other slope positions, which could have been caused by the higher level of nutrients in the soil from this position. The above results clearly show that land use and soil management practices influence soil erosion and the processes such as oxidation, mineralization, and leaching of nutrients and other soil chemicals (Wang *et al.*, 2001), thus modifying the processes of transport and re-distribution of nutrients, OM and soil carbonates. The patterns of water and tillage erosion across the landscapes were found to be mainly dependent on topographic features and they were fundamentally different within topographically complex landscapes (Li *et al.*, 2007).

Agronomic Productivity of Soils

The analysis of variance (Table II) showed that the effect on yield and yield components of wheat of all investigated factors of land use, slope position, water stress and fertilizer, as well as most of their interactions were significant at $P \leq 0.01$ or $P \leq 0.05$ levels.

Individual effects of treatments

The results of mean comparison of yield and yield components of wheat for different treatments, shown in Table III, suggest that; (i) all the yield components of wheat were significantly lower in the rangeland than the dry farmland soils, and in the water stress treatment than without, (ii) dry matter, grain yield and grain number were all significantly higher on the lower slope than on the upper slopes, but reverse was the case for grain weight, (iii) chemical fertilization and chemical+manure fertilization significantly increased wheat yield and yield components, and (iv) the effect of chemical+manure was significantly higher for dry matter and grain number than the effect of chemical fertilizer.

The higher yield in farmland soils compared to the rangeland appears to be directly related to the soil fertility status. As shown in Figure 2, most measured fertility indicators including macronutrients, OM, CEC and CCE were better in the dry farmland than in the rangeland soils. The same is the case for the effects of landscape position on wheat yield, as it was higher at the lower slopes where soil fertility was higher (Figure 2). Soils taken from the midupward slope position in our study yielded the lowest wheat dry matter and grain yield compared with the soils taken from other slope positions. This slope position had the steepest slope gradient, and higher erosion rate thus showing the lowest soil fertility (Figure 2).

Interactive effect of treatments

There was an interactive effect between land use type and slope position on grain yield and grain weight (Table II). Although both were higher in the farmland than the rangeland on all slope positions, the differences between two land use types were higher at the up- and foot-slopes than at the mid-slope (Figure 3).

There was no significant difference among the slope positions under water stress condition, but grain yield at the midupward slope position was lower than the other slope positions under no water stress condition. Grain number was also affected in the same way by slope position×water stress (Figure 4). These results show that the true impact of soil degradation on soil productivity is overshadowed by drought, which is a common phenomenon in the arid and semiarid regions of Iran as also reported by Mehdizadeh *et al.* (2010).

Results indicate that water stress decreases dry matter, grain yield and grain number more in the farmland than in the rangeland soils (Figure 5), which suggest that the differences between wheat yield on both landscape types is higher when there is adequate water supply, although this water stress effect is insignificant for grain number. Water stress could partially overshadow the influence of other factors such as nutrients, CEC and OM on crop yield, which were shown before to be significantly higher in the farmland than the rangeland soils (Figure 2) and resulted in significantly higher wheat yields (Table III).

The interactions between land use and fertilizer application shows that fertilizers increase wheat growth and yield more efficiently in the degraded soils of rangeland than in the farmland (Figure 6). While the dry matter in the rangeland soils was about 32 percent lower than in the farmland soils under no fertilizer treatment, this difference was reduced to 13% and zero respectively for fertilizer and fertilizer+manure treatments (Figure 6). Similar results were obtained for the interactive effect of land use×fertilization for grain number (Figure 6). These results show the importance of organic matter (manure) in improving soil quality and increasing the productivity of the degraded soils.

For the grain yield, there was no significant difference between chemical fertilization and chemical+manure fertilization (Figure 6). Fertilization increased grain yield by 19 and 95 percent in the farmland and rangeland soils, respectively.

Figure 7 shows that fertilizer and fertilizer+manure increased dry matter and grain weight more at the upper slopes than on the lower slopes. The soils taken from upper slopes had lower fertility (Figure 2) than those taken from lower slopes and consequently responded to fertilizer application more efficiently. Similar results were observed when comparing the responses of degraded soils of rangeland and farmland soils to fertilizer as shown in Figure 6.

The mean comparison of the water stress×fertilization interaction for yield components (Figure 8) clearly showed that water stress significantly reduces fertilizer efficiency for all yield components of wheat. Other researchers have also found that fertilizer efficiency is severely affected by water availability or water stress (Salvagiotti *et al.*, 2009; Mehdizadeh *et al.*, 2010).

CONCLUSION

All the indicators of soil health and productivity were higher in the soil samples taken from the dry farmland than those taken from the adjacent degraded rangeland. Soil and crop management practices such as manure application and crop husbandry carried out on the farmland, coupled with the severe overgrazing of the rangeland appear to be responsible for the observed differences between the two soil management types. Also the soils from footslopes were of better quality and productivity due to higher OM and nutrient contents, higher CEC and lower CCE compared with soils from other

locations on the slopes. Accumulation of transported OM and fine particles from upslopes by erosion can improve the quality of soils in the footslopes.

Yield components of wheat were all higher in the dry farming soils as compared with the degraded rangeland soils, and in the soils from lower slopes than from upper slopes. The differences in yield and yield components between the two land use types were generally higher in the soils from the top and foot slopes than from the middle slope. Both nutrient availability and soil properties associated with slope position and land use influence soil agronomic productivity.

The effect of land use type and slope position on agronomic productivity is influenced by water supply. True impact of soil degradation induced by land use and slope position on soil productivity was overshadowed by the dominant effect of water stress. Water stress also reduced the efficiency of chemical fertilizer in increasing yield. While both chemical fertilizer and fertilizer+manure treatments enhanced soil agronomic productivity of soils, their effects were more pronounced on the degraded soils of rangelands than the farmland soils.

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Table I. Some of the general properties of the soil samples

Land use	Slop position	Clay (%)	Silt (%)	Sand (%)	Soil Texture	Bd (g cm ⁻³)	FC (%)	pH
Dry farming	1 (up)	28	49	23	CL	1.29	31.1	7.4
	2	32	50	18	SiCL	1.27	30.6	7.3
	3	31	51	18	SiCL	1.26	31.7	7.3
	4 (down)	32	54	14	SiCL	1.22	32.6	7.3
Degraded range	1 (up)	32	49	19	SiCL	1.25	31.0	7.4
	2	22	54	24	SiL	1.25	30.8	7.5
	3	25	54	21	SiCL	1.23	31.0	7.4
	4 (down)	24	52	24	SiL	1.22	31.5	7.4

Table II. Analysis of variance of wheat yield and yield components

S.O.V.	df	Mean square			
		Dry matter (g plant ⁻¹)	Grain yield (g plant ⁻¹)	Number of grain (plant ⁻¹)	Grain weight (g 1000 ⁻¹)
L.U	1	2.39**	1.84**	431.43**	1447.04**
S.P	3	0.41**	0.07**	132.58**	164.30**
W.S	1	27.07**	9.28**	6982.69**	1039.63**
F	2	5.80**	0.62**	543.53**	101.98**
L.U × S.P	3	0.01 ^{ns}	0.04*	26.70 ^{ns}	34.47*
L.U × W.S	1	0.45**	0.50**	193.09**	14.41 ^{ns}
L.U × F	2	0.89**	0.11**	160.16**	19.31 ^{ns}
S.P × W.S	3	0.05 ^{ns}	0.03*	46.75*	2.24 ^{ns}
S.P × F	6	0.17*	0.02 ^{ns}	24.19 ^{ns}	33.88**
W.S × F	2	0.83**	0.31**	233.53**	3.21 ^{ns}
L.U × S.P × W.S	3	0.05 ^{ns}	0.02 ^{ns}	66.28**	11.88 ^{ns}
L.U × S.P × F	6	0.05 ^{ns}	0.03*	35.69*	13.16 ^{ns}
L.U × W.S × F	2	0.05 ^{ns}	0.02 ^{ns}	21.70 ^{ns}	14.52 ^{ns}
S.P × W.S × F	6	0.07 ^{ns}	0.02 ^{ns}	23.12 ^{ns}	26.48**
L.U × S.P × W.S × F	6	0.03 ^{ns}	0.03*	40.67**	13.03 ^{ns}
E.E	96	0.06	0.01	13.03	8.83
CV	143	14.22	17.05	17.18	11.13

S.O.V.= sources of variation; df= degree of freedom; L.U= land use; S.P= slope position; W.S= water stress; F= fertilizer; E.E= experimental error; CV= coefficient of variation.
Symbols in superscript represent significance of effects: ns, non significant; *, $P \leq 0.05$; **, $P \leq 0.01$.

Table III. Yield and yield components of wheat as affected by land use, slope position, fertilizer and water stress.

Treatment	Dry matter (g plant ⁻¹)	Grain yield (g plant ⁻¹)	Grain number (plant ⁻¹)	Grain weight (g 1000 ⁻¹)
Land use				
Dry farmland	1.89 ^a	0.70 ^a	22.75 ^a	29.85 ^a
Rangeland	1.63 ^b	0.47 ^b	19.28 ^b	23.51 ^b
Slope position				
Up slope	1.73 ^b	0.60 ^a	18.90 ^b	29.78 ^a
Midupward slope	1.62 ^{ab}	0.52 ^b	19.89 ^b	25.18 ^b
Middownward slope	1.84 ^a	0.61 ^a	22.86 ^a	25.36 ^b
Foot slope	1.85 ^a	0.62 ^a	22.40 ^a	26.42 ^b
Fertilizer				
Non-fertilization	1.40 ^c	0.46 ^b	17.28 ^c	25.04 ^b
Chemical fertilization	1.80 ^b	0.64 ^a	21.95 ^b	27.19 ^a
Chemical+manure	2.09 ^a	0.66 ^a	23.81 ^a	27.82 ^a
Water				
Without stress	2.19 ^a	0.84 ^a	27.97 ^a	29.37 ^a
Water stress	1.33 ^b	0.33 ^b	14.05 ^b	24.00 ^b

For each treatment, values with the same letters within columns are not significantly different by Tukey's test at $P \leq 0.05$.

Figure 1. (a) Location of the study area within Iran, and (b) topographical variation of the study area.

Figure 2. The mean comparison of land use/slope position interaction for (a) organic matter, (b) total nitrogen, (c) Available phosphorous, (d) available potassium, (e) cation exchange capacity, (f) calcium carbonate equivalent and (g) rock fragment, and (h) mean comparison of slope position effect on mean weight diameter of soil aggregates and electrical conductivity. Mean values with the same letters are not significantly different by Tukey's test at $P \leq 0.05$.

Figure 3. The mean comparison of land use x slope position interaction for wheat grain yield (a) and grain weight (b). Mean values with the same letters are not significantly different at $P \leq 0.05$.

Figure 4. The mean comparison of slope positionxwater stress interaction for wheat grain yield (a) and grain number (b). Mean values with the same letters are not significantly different at $P \leq 0.05$.

Figure 5. The mean comparison of land use×water stress interaction for wheat dry matter (a), grain yield (b) and grain umber (c). Mean values with the same letters are not significantly different at $P \leq 0.05$.

Figure 6. The mean comparison of land use × fertilizer interaction for wheat dry matter (a), grain yield (b) and grain number (c). Mean values with the same letters are not significantly different at $P \leq 0.05$.

Figure 7. The mean comparison of slope position×fertilizer interaction for wheat dry matter (a) and grain weight (b). Mean values with the same letters are not significantly different at $P \leq 0.05$.

Figure 8. The mean comparison of fertilizer×water stress interaction for wheat dry matter (a), grain yield (b) and grain number (c). Mean values with the same letters are not significantly different at $P \leq 0.05$