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Impact of erosion and tillage on the productivity and quality of selected semiarid soils of Iran

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A b s t r a c t. This greenhouse research was carried out to study the effects of water and tillage erosion on agricultural productivity and soil quality in soil samples from a semiarid region of Iran. A factorial experiment of complete randomized block design was used to compare the effects of soil erosion (eroded and non-eroded soils), slope position, water stress and fertilizer (N-P-K) on yield and yield components of wheat as soil productivity index. The results showed that erosion *ie* water and tillage erosion has a significant effect ($p<0.01$) in decreasing soil productivity due to its negative impact on soil organic matter, nutrients (N and K) and hydraulic conductivity. Complete N-P-K fertilization and water stress had significant effects on increasing and decreasing of wheat yield, respectively. The effect of water stress in particular was so high that it could eclipse the erosion impact on yield reduction. Wheat dry matter and grain mass on foot and mid slopes were significantly higher than that on upslope positions where total N and available K were the lowest and equivalent calcium carbonate the highest. Saturated hydraulic conductivity and total nitrogen were found to be the most important soil properties as far as their correlations to wheat yield are concerned.

K e y w o r d s: slope position, greenhouse experiment, wheat, fertilizer, water stress

INTRODUCTION

More than 60% of Iran farm lands are under dryland farming of wheat, barley and other cereal crops. The area under dryland farming of wheat alone is around 4 to 5 mln ha (Agricultural Statistics of Iran, 1998). A large fraction of Iran cultivated lands (dryland and irrigated) is devoted to wheat and barley which are the main sources of staple food and protein for the average Iranian. Wheat alone covers about one third and fruit tree plantations cover nearly one fifth of the total irrigated lands of Iran. Cereal crops *ie* wheat, barley, and rice) cover almost 70% of the cultivated land, while wheat alone covers nearly 52%. In Iran, it is a well established fact that the average yield of different crops is much higher under irrigated system than under dryland farming. For example, the average yield of irrigated wheat is about 3 200 kg ha^{-1} while under dryland farming this figure is below 1 000 kg ha^{-1} (Siadat, 1998).

Erosion is very severe in the semiarid and drylands regions of Iran due to high erodibility of the soil and poor vegetation cover. The increasing population and the need for more food and fibre have pushed farmers to use lands which are not suitable for farming, especially on steep slopes (Ahmadi-Iikhchi *et al*., 2003). Many grasslands have also been destroyed due to high stocking rate and over-grazing, resulting in severe soil degradation (Asadi *et al*., 2012).

Soil erosion, in the form of mass downslope transport, is also intense under the conventional tillage systems which employs the mouldboard plough (Alvarez *et al*., 1995), still the most common form of tillage in Iran. On-site impact of accelerated soil erosion includes short-time reduction in crop yield and long-time decline in soil agronomic productivity and soil quality (Lal, 1998). Erosion-induced decline in soil quality causes the reduction in effective rooting depth, decline in plant available water capacity, decline in soil biodiversity, reduction in soil organic matter pool (Kaihura *et al*., 1999; Lal, 1998), and decrease in soil holding capacity of heavy metals (Stępniewska *et al*., 2009). Erosion also influences other soil properties, including nutrient status, soil structure and water holding and transmission characteristics (Kaihura *et al*., 1999).

Soil carbon loss by combined effect of tillage and erosion (Moussa-Machraoui *et al*., 2010) contributes to greenhouse gas emissions and decrease in the production capacity

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of soils (Boellstorff, 2009). It has been estimated that soil quality decline represents an annual loss of 0.3% of the value of the global production of selected crops (Den Biggelaar *et al*., 2003). Achieving sustainable management of eroded soils requires information on the magnitude of yield reduction associated with soil loss and the changes in the physical and chemical properties resulting from erosion (Oyedele and Aina, 1998), particularly for low technology-input agricultures. There is also the need to identify some easily measurable soil physical and chemical properties that are sensitive to erosion. This will ensure an early detection of soil erosion and a quick response to managing such soils before they are completely degraded.

Generally, erosion rate and loss of soil quality depend on climatic conditions during the growing season, land and crop management and cultivation practices. Thus the relation between erosion and soil productivity is highly complex. Accordingly, various methods have been used to assess erosion impacts on soil productivity. This paper reports on a research work carried out to study the effects of accelerated erosion on the agronomic productivity of two sets of calcareous soil samples from a semiarid region of Iran. Yield and yield components of wheat were determined as soil productivity index and the effects of fertilizer and water stress were also studied.

MATERIALS AND METHODS

The relative impact of accelerated soil erosion on agronomic productivity of soils was studied for two sets of soil samples from a semiarid region of Iran in a greenhouse experiment; one set obtained from cultivated fields with long term conventional up-down tillage and the other obtained from the adjacent permanent grasslands. The soil samples from cultivated fields were regarded as under accelerated soil erosion and ones from the adjacent grassland as non-eroded or under natural soil erosion. Criteria for such central assumption were based on visual survey of erosion types including sheet and rill erosion and tillage mass movement which had caused a level difference of about 50 cm between the cultivated field and adjacent grassland at the upslope in the case of our sampling areas.

Soil samples were taken from two hill slopes (36°22' 35”N, 49°35'02”E; 1454 m and 36°22'00”N, 49° 36' 27” E: 1 350 m) in Kuhin region, Qhazvin province. The mean annual precipitation and temperature of the region are 325 mm and 12.5°C, respectively. The mean annual potential evaporation is about 1 200 mm.

Six soil samples (three pairs) from 0-20 cm depth were collected from the upper, middle and foot slopes of each hill slope, each pair from a slope position, one sample from dry farming field as eroded soil and the other from adjacent grassland in the same slope position as non-eroded soil. The average slope steepness was 20, 15 and 10% for the upper, middle and foot slope positions, respectively. Soil samples were obtained after crop harvest. Overall, 12 soil samples from two landscapes were collected and transported to the laboratory. The samples were air dried and a subsample with the mass of about 2 kg was ground and passed through a 2 mm sieve in preparation for chemical and physical analysis. Measured properties were bulk density (Clod method), soil texture (hydrometer method), soil water content at saturation percentage (SP), field capacity (FC) and permanent wilting point (PWP) using pressure plate, pH in KCl solution, total nitrogen (N) (Kjeldhal-N method), available phosphorous (P) by Olsen method, 1 M NH_4OAC extractable potassium (K), organic matter content (OM) by Walkly and Black method, equivalent calcium carbonate (CCE) (neutralization with HCl), saturated hydraulic conductivity (K_s) determined by constant head procedure on core samples, and electrical conductivity (EC) of saturated extract. All the measured methods are described in Klute (1986) and Sparks (1996).

A factorial completely randomized design with three replications was used in this greenhouse experiment to compare the effect of four factors on yield and yield component of wheat. The factors were soil erosion (eroded and non-eroded soil samples), slope position (lower, middle and upper slopes), water stress (with and without stress) and fertilizer (non-fertilization and complete fertilization). Urea, super phosphate triple and potassium sulphate were used in the complete fertilization pots at the rates of 130, 150 and 250 kg ha^{-1}, respectively. Water stress applied from the beginning of earing (end of shooting stage) to the end of growth period by doubling of irrigation period in the water stress treatment compared to non-stressed treatment in which irrigation was done in the depletion limit of 50±2.5% of available water by weighing the pots. In this case, plants in the pots with limited irrigation showed signs of water stress including physiological symptoms such as leaves welt, darkness and tortuous appearance before next irrigation.

A spring wheat (*Triticum aestivum* L. cv. Atrak) was planted with the density of four plants per pot (5 kg capacity). At the end of the growth period, above ground dry matter, grain yield, grain number and grain mass were determined. The results obtained were analyzed according to the algorithms of SAS software (Statistical Analysis System, 1996). Multiple regression analysis was also used to find any relation that may exist between agronomic productivity and soil properties. To cover any discrepancy between wheat yields in the two landscapes due to unknown factors, the data were normalized and yield ratio was considered as dependent variable rather than the absolute yield. To compute the yield ratio, average yield of each soil sample was divided to the maximum yield among all soil samples on each landscape. Since the effect of soil properties, including nutrient content and water holding capacity, may have been affected by fertilizer and water stress treatments, regression analysis was separately performed for different fertilizer and water stress treatments, in addition to analysing the entire data set.

RESULTS AND DISCUSSION

Soil texture was clay loam to silty clay loam for all samples, and electrical conductivity of the saturated extract ranged from 0.1 to 0.15 dS m^{-1}. The effects of land use and slope position on soil properties is summarises in Table 1. The results show that K_S, total N, available K, total soil OM and FC are all lower in the farmland than in the grassland. Higher bulk density (Bd) and calcium carbonate contents occurred in cultivated land than the grasslands. Organic matter content under arable lands tends to be lower than under non-arable lands confirming that erosion and soil degradation are higher in cultivated lands than grassland (Szilassi *et al*., 2006). The results also indicate that cultivation decreases soil nutrient levels, as has been noted by many authors (Wang *et al*., 2001). Soil tillage usually induces a reduction in aggregates size (Czyż and Dexter, 2008, 2009), which leads to change in pore sizes and their connectivity and, consequently, affects soils hydraulic conductivity (Strudley *et al*., 2008). As it is observed in Table 1, the saturated hydraulic conductivity content is higher in the foot slope regardless of the same amount of clay in up and down slope. In fact, K_S depends on different factors including clay and sand amount, Bd, pore size, particles size distribution, OM and CCE. Although, some of these factors *eg* clay content are almost constant in different parts of the slope, the results show that the sand percentage increases from up to foot slope. What is more, the amount of CCE has a decreasing trend from upper part of slope to down slope. So, being higher, K_S in the foot slope can be affected by sand and CCE content. Though contradictory results had been reported on the effect of tillage systems on soil bulk density, as reviewed by Alvarez and Steinbach (2009), crops roots growth can be adversely affected when soil bulk density reaches 1.5 g cm^{-3} (Hassan *et al*., 2007).

As shown in Table 1, the landscape slope position also had some effect on soil properties. Organic matter content, total N and available K were higher at the foot slope than the upslope. However the CCE was higher at the upslope (22.7%) than mid and foot slope (18.1 and 18.6%, respectively). This finding corresponds with those of Asadi *et al*. (2012). Land use and soil management practices influence the process of erosion and the processes of oxidation, mineralization, and leaching of OM and nutrients (Wang *et al*., 2001), and consequently modify the processes of transport and re-distribution of nutrients, OM and soil carbonates.

The results of statistical analysis indicated that all the investigated factors, including erosion (land use), fertilizer, water stress ($p<0.01$) and slope position ($p<0.05$), had significant effect on aboveground dry matter. Dry mater was also affected significantly ($p<0.01$) by the interactive effect of erosion×water stress and fertilizer×water stress. Also significant effect ($p<0.01$) of erosion, fertilizer, water stress and fertilizer×water stress on grain yield and grain number were observed. Generally, all yield components were affected significantly by erosion and this indicates that erosion has an important role in decreasing agronomic productivity of soil.

The t-test carried out on the mean values indicated that all the yield components of wheat crop are significantly lower in the eroded soil samples than the non-eroded

T a b l e 1. Effects of slope position and land use on soil properties

Property	Slope position*						Average	
	Up		Mid		Foot			
	Erosion							
	Eroded[1]	Non-eroded[2]	Eroded[1]	Non-eroded[2]	Eroded[1]	Non-eroded[2]	Eroded[1]	Non-eroded[2]
Clay (g kg^{-1})	370	380	370	390	390	370	377	380
Sand (g kg^{-1})	215	260	235	230	245	200	232	230
Total N (g kg^{-1})	0. 66	0.85	0.76	0.90	0.91	1.09	0.77	0.94
Available K (mg kg^{-1})	154	192	201	246	210	348	189	262
Available P (mg kg^{-1})	23	22	23	20	22	26	22.7	22.7
OM (g kg^{-1})	7.4	9.9	7.5	9.9	7.4	14.2	7.4	11.3
$CaCO_3$ (g kg^{-1})	229	224	184	177	189	183	201	195
K_s 10^3 (cm s^{-1})	0.89	3.04	1.85	2.53	1.76	2.27	1.50	2.62
Bd (Mg m^{-3})	1.54	1.47	1.58	1.52	1.53	1.47	1.55	1.48
FC (g kg^{-1})	305	307	294	296	285	295	295	299

[1]dry farm, [2]grassland, *data were averaged for two landscapes.

samples (Table 2). The reason for such reduction in yield is the loss of productive top soil due to water erosion and downslope soil mass movement by tillage (Table 1). Soil erosion has been previously recognized as a major factor in land degradation, especially in the reduction in productivity and OM content of soils (Fenton *et al*., 2005). The results also show that fertilization significantly increases aboveground dry matter, grain yield and grain number, but has no effect on grain mass (Table 2). In contrast, water stress significantly decreased dry matter, grain yield and grain number, and had no effect on grain mass (Table 2).

There were no significant differences in grain yield and grain number among the landscape positions, but significant differences were observed among landscape positions for aboveground dry mater ($p<0.01$) and grain mass ($p<0.05$). Comparisons of the yield and yield components by landscape positions (Fig. 1) revealed that dry matter and grain mass are significantly higher on the samples taken from foot and mid slope positions than those taken from upslope. The lowest levels in dry matter and grain mass occurred on the upslope position where total N and available K were the lowest and equivalent calcium carbonate was the highest (Table 1). This higher crop yield on the lower slope position could be due to the deposition of soil and nutrients transported from the upslope positions by surface wash and tillage. Apart from the deposition of materials, the footslope position is usually associated with deeper profile and more favourable moisture conditions compared to the upper and mid slope positions (Oyedele and Aina, 1998).

The significant interaction observed between erosion and water stress ($p<0.01$, for dry matter and grain yield; and $p<0.05$, for grain mass) means that the effect of soil erosion on yield and yield components of wheat was different for irrigation treatments. There was no significant difference between the effect of erosion on yield and yield components of wheat under limited water application (Fig. 2). However, under adequate water supply *ie* without stress treatment, dry matter and grain yield of wheat were both higher on the non-eroded soils than on the eroded ones. These results clearly show that the true impact of soil degradation by water erosion and tillage mass movement on soil productivity can be overshadowed by drought, which is a common phenomenon in the arid and semiarid regions of Iran.

There was also a significant interactive effect between water supply and fertilized treatments on dry matter, grain yield and grain number ($p<0.01$). Fertilization increased dry matter, grain yield and grain number by 32, 21 and 14%, respectively, under limited water condition, whereas under adequate irrigation condition these increases were 52, 57 and 54%, respectively (Fig. 3). This means that fertilizer efficiency is low in dry years (or under drought conditions) compared to wet years. On the other hand, wheat yield in the complete fertilization under water stress treatment was equal to (grain yield and grain number) or even higher than (dry matter) that in the non-fertilization-non-stress treatment. Fertilization generally decreased the effect of water stress on wheat yield or increased crop resistance to water stress.

It has been established that there is some interaction among various inputs *eg* tillage treatments and fertilizers (Alvarez and Steinbach, 2009), water supply and fertilizer

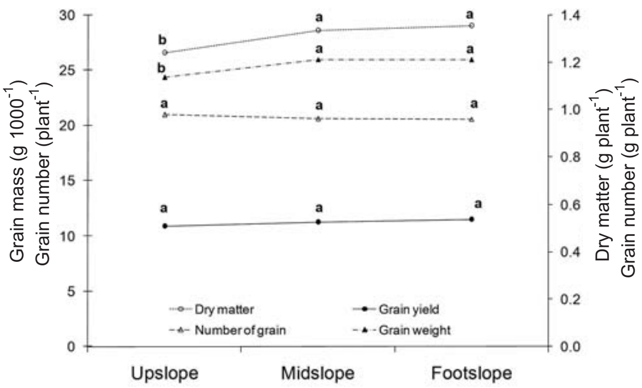

Fig. 1. Yield and yield components of wheat as affected by slope position.

T a b l e 2. Yield and yield components of wheat as affected by erosion, fertilizer and water stress

Treatment		Dry matter	Grain yield	Grain number	Grain mass
		(g plant^{-1})		(plant^{-1})	(g 1 000^{-1})
Erosion	Non-eroded soil	1.395a*	0.565a	21.844a	26.137a
	Eroded soil	1.223b	0.483b	19.593b	24.729b
Fertilizer	Complete fertilization	1.538a	0.612a	23.815a	25.936a
	Non-fertilization	1.080b	0.436b	17.622b	24.930a
Water	Without stress	1.441a	0.601a	23.572a	25.698a
	Water stress	1.178b	0.447b	17.865b	25.167a

*For each treatment means values with the same letters within columns are not significantly different at $p<0.05$.

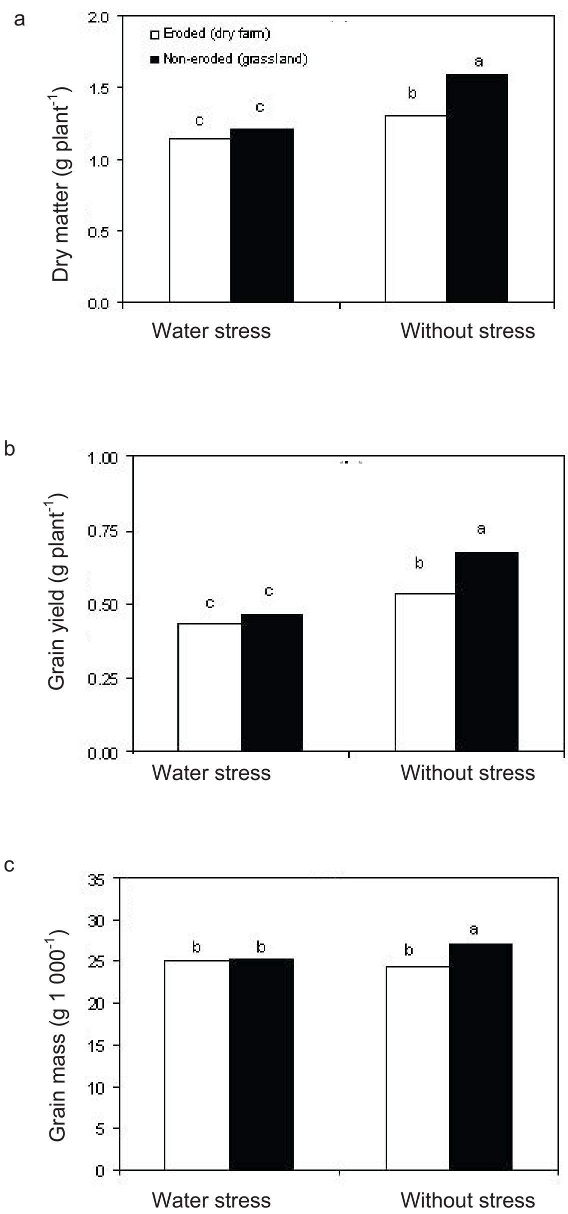

Fig. 2. Yield and yield components of wheat as affected by erosion × water stress: a – dry matter, b – grain yield, and c – grain mass.

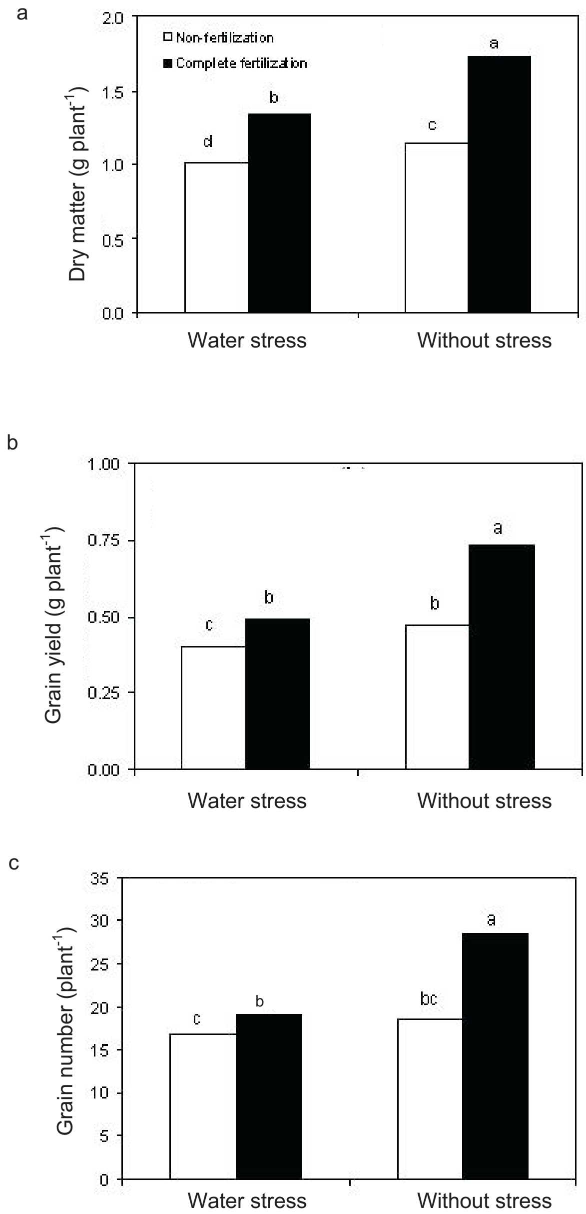

Fig. 3. Yield and yield components of wheat as affected by fertilizers × water stress: a – dry matter, b – grain yield, and c – grain mass.

(Asadi *et al*., 2012) and various agronomic and management practices including water supply and nitrogen (Kalra *et al*., 2007), on growth and yield of wheat. Anderson (2010) also analyzed the relative and individual importance of environmental factors (rainfall, temperature, radiation *etc*.) management practices (including the choice of crop and cultivar, fertilizer amount and timing, weed, insect and disease control) and cultivars for yield improvement of wheat and emphasized the interactions among them.

Multiple regression analysis (Table 3) shows that aboveground dry matter ratio is correlated to different soil properties for different treatments. Dry matter is significantly correlated to hydraulic conductivity, total N and available P when analysing all data points lumped. In the complete fertilization treatment, there was a high degree of correlation between dry matter and hydraulic conductivity and available P and K, but in the non-fertilization treatment, OM, available P, and bulk density had the best correlation with dry matter. While dry matter was correlated to hydraulic conductivity and available P and K in no water stress treatment, in the water stress treatment total N was the only soil property correlated to dry matter. Once again, it appears as though water stress acts as limiting factor and conceals the effect of soil properties on its productivity.

T a b l e 3. Correlation coefficients and regression equations of wheat dry matter ratio to soil properties in various treatments

Treatments		Multiple regression equation	No. equations	R^2
Total data		R_{DM}=0.419+61.035K_s+2.021N+0.007P	(1)	0.79
Non-fertilization		R_{DM}=0.2952+6.24N	(2)	0.60
Complete fertilization		R_{DM}=0.541+49.186K_s+0.0079P+0.0003K	(3)	0.80
Without water stress		R_{DM}=0.191+106.028K_s+0.0151P+0.0004K	(4)	0.83
With water stress		R_{DM}=0.62+3.32N	(5)	0.64
Non-fertilization	without stress	R_{DM}=0.261+6.22N	(6)	0.47
	water stress	R_{DM}=0.295+6.393N	(7)	0.73
Compelete fertilization	without stress	R_{DM}=0.338+76.85K_s+0.0106P+0.0006K	(8)	0.85
	water stress	R_{DM}=0.8998+0.0582OM	(9)	0.20

R_{DM} – dry matter ratio (obtained on each soil sample to the maximum value), K_s – saturated hydraulic conductivity, N – total nitrogen, P – available phosphorous, K – available potassium, OM – organic matter.

T a b l e 4. Correlation coefficients and regression equations of wheat grain yield ratio to soil properties in various treatments

Treatments		Multiple regression equation	No. equations	R^2
Total data		R_{GY}=0.51+63.946K_s+2.751N	(10)	0.72
Non-fertilization		R_{GY}=0.328+72.299K_s+4.089N	(11)	0.64
Complete fertilization		R_{GY}=0.751+71.009K_s	(12)	0.62
Without water stress		R_{GY}=0.357+125.878K_s+0.01P	(13)	0.76
With water stress		R_{GY}=0.591+3.302N	(14)	0.48
Non-fertilization	without stress	R_{GY}=0.501+134.428K_s	(15)	0.51
	water stress	R_{GY}=1.094+5.932N-0.508ρ_b	(16)	0.75
Compelete fertilization	without stress	R_{GY}=0.579+83.92K_s+0.00044K	(17)	0.75
	water stress	No significant correlation was observed	(18)	–

R_{GY} – grain yield ratio (obtained on each soil sample to the maximum value), ρ_b – bulk density. Other explanations as in Table 3.

Whatever could be quite different in the field conditions, available P, total N, K_s and OM are the most important soil properties positively correlated to dry matter ratio in this greenhouse experiment. Though nutrient effect is expected and does not call for any discussion, the effect of saturated hydraulic conductivity requires some explanation. It may be due to the fact that soils with higher K_s have better aeration, and K_s therefore could be consider as an index of soil aeration. The highest and the lowest correlations were observed for complete fertilization without water stress and non-fertilization with water stress treatments, respectively.

Table 4 presents the results of regression analysis for grain yield ratio. Similar to the dry matter, grain yield too was correlated to different soil properties for different treatments. In this case, saturated hydraulic conductivity (K_s) was the most important soil property positively correlated to grain yield, followed by total nitrogen. Saturated hydraulic conductivity and total N appeared in most of the Eqs (10) and (9) out of Eq. (17), respectively (Tables 3 and 4), but to determine whether they are the most important indicators of soil productivity requires more evaluation with more soil samples.

CONCLUSIONS

1. Long term effect of conventional tillage practice and its consequent soil erosion (downslope mass transport of soil) on the properties and agronomic productivity of soils was investigated. The results showed that some of the soil properties, including organic matter content, total N, available K, and hydraulic conductivity are lower in the dry farmed field with conventional tillage than the adjacent permanent grassland.

2. The soil agronomic productivity, evaluated by measuring wheat yield in a greenhouse experiment, was affected significantly by land use, slope position, fertilization and water use. Yield and yield components of wheat were significantly lower on the eroded than on the non-eroded soils. Fertilization significantly increased dry matter, grain yield and grain number, but had no effect on grain mass. In contrast, water stress significantly decreased dry matter, grain yield and grain number, and had no effect on grain mass. There was no significant difference between the effect of soil

erosion on yield and yield components of wheat under water stress. There was also a significant interactive effect between water supply and fertilization treatments on dry matter, grain yield and grain number.

3. The results clearly showed that the true impact of soil degradation by water erosion and tillage practice on soil productivity could be hidden in the arid and semiarid regions where drought is a common phenomenon.

4. Saturated hydraulic conductivity and total nitrogen were found to be the most important soil properties as far as their correlations to wheat yield are concerned in the greenhouse conditions.

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