RAINFALL WATER USE EFFICIENCY OF WINTER WHEAT IN A SEMI-ARID REGION IN NW IRAN

EFFICACITE DE L'UTILISATION DE L'EAU PLUVIALE DANS LA CULTURE DU BLE D'HIVER DANS UNE REGION SEMI-ARIDE AU NORD-OUEST D'IRAN

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ABSTRACT

Crop production and water use efficiency in semi-arid regions is low due to water stress resulting from low and erratic rainfall. This study was conducted in a semi-arid agricultural region with 900 km^2 area in Hashtroud, north west of Iran to determine the relationship between rainfall water use efficiency of wheat and soil properties. Thirty six dry-farming lands with a uniform slope 9% were selected in the area. Wheat yield and soil properties were determined at 3 plots (each 40.41 m^2) in each dry land. Mean annual rainfall was 140.7 mm during 2-year period. Analysis of rainfall data in four rain gauge stations in the area showed that there was no significant difference among them and so spatial distribution of rainfalls was uniform and in consequence, variations of wheat grain yield among dry lands were directly related to their soil type. Soils were mainly clay loam containing 1.1% organic matter and 12.7% carbonates. Wheat grain yield varied between 801.4 kg ha^{-1} and 3484.3 kg ha^{-1} in dry lands. Rainfall water use efficiency (RWUE) in 36 dry-farming lands ranged from 0.35 kg m^{-3} to 1.49 kg m^{-3} with an average of 0.84 kg m^{-3}. Multiple regression analysis indicated that RWUE was significantly related to silt, organic matter and lime (R^2 = 0.82, $p<0.001$). Organic matter and lime, contrary to silt, enhanced aggregate stability and soil infiltration rate and consequently increased water availability to plant root.

Keywords: *Organic matter; Lime, Infiltration; Dry land*

RESUME

La production agricole et l'efficacité d'utilisation de l'eau dans les régions semi-arides est faible en raison de stress hydrique résultant des précipitations faibles et irrégulières. Cette étude a été menée dans une région semi-aride agricole de 900 km^2 dans la zone d'Hashtroud, au nord-ouest de l'Iran afin de déterminer la relation entre l'efficacité de l'utilisation de l'eau

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pluviale dans la culture du blé d'hiver et des propriétés du sol. Trente-six terres à l'agriculture sèche avec une pente uniforme de 9%, ont été sélectionnées dans la région. Le rendement du blé et des propriétés du sol ont été déterminés à 3 parcelles (40,41 m^2) dans chaque morceau de terre sèche. La précipitation moyenne annuelle a été 140,7 mm pendant deux ans. L'analyse des données sur les précipitations dans les quatre stations pluviométriques dans la région a montré qu'il n'y avait aucune différence significative entre eux et donc la distribution spatiale des précipitations était uniforme. En conséquence, les variations du rendement en grains de blé parmi les terres arides étaient directement liées à leur type de sol. Les sols sont principalement limon argileux contenant 1,1% de matière organique et des carbonates de 12,7%. Le rendement en grain de blé a varié entre 801.4 kg ha^{-1} et 3484.3 kg ha^{-1} dans les terres sèches. L'efficacité de l'utilisation de l'eau pluviale (RWUE) en 36 terres sèches agricole des terres variait de 0,35 kg m^{-3} à 1,49 kg m^{-3} avec une moyenne de 0,84 kg m^{-3}. L'analyse de régression multiple a indiqué que RWUE était significativement liée à limon, les matières organiques et de chaux (R^2 = 0,82, p <0,001). La matière organique et celle de la chaux, contrairement à limon, a amélioré la stabilité totale et le taux d'infiltration des sols et conséquemment la disponibilité de l'eau à la racine des plantes.

Mots clés: *Matière organique, chaux, infiltration, terres sèches.*

1. INTRODUCTION

Precipitation is one of the most important factors affecting agricultural production, especially in the arid and semi-arid regions. Rainfall water use efficiency (RWUE) is the ratio of crop dry matter per unit of abstracted rainfall water volume (ARWV). The abstracted rainfall water volume is a part of precipitation that could be stored in soil. Rainfall water use efficiency (RWUE) decreases when runoff increases. Runoff occurs when the rate of rainfall exceeds the infiltration rate of soil (Schwab et al., 1993). Runoff in the arid and semi-arid regions occurs when rainfall intensities are high and the soil infiltration capacity is reduced because of surface sealing. The rate of infiltration of water into the soil depends on several soil properties, particularly physical characteristics of the soil (Ghawi and Battikhi, 1986). Factors affecting RWUE may be divided into those factors associated with the rainfall properties, and those with soil physic-chemical properties. In a definite area with different soils that receive the same values of precipitation, the RWUE is directly affected by soil physic-chemical properties.

Almost 39% of the geographical area of Iran (642797 km^2) has a semi-arid climate condition, with an annual precipitation between 200 and 500 mm. Farming is mostly done in dry condition and crop production is wholly dependent on rain water storage in soil. Wheat production under rainfed conditions is low and consequently, a major research challenge is to investigate factors that maximize the RWUE. The objective of this work is to quantify the influence of soil properties on the RWUE in dry-farming lands of semi-arid regions.

2. MATERIALS AND METHODS

Study area

The study was carried out in a semi-arid area of NW Iran located in Hashtroud township (southern part of East Azarbyjan province) from March 2005 to March 2006. The study zone was 900 km^2 in area located between 37° 18' 49" and 37° 35' 0" N latitude, and 46° 46' 5" and 47° 6' 5" E longitude (Fig. 1). The climate is semi-arid with an average annual precipitation of 322 mm, mostly falling in the winter, autumn and spring and a mean annual temperature of 13°C. Agricultural soils located mostly in 5-15% slopes and are mainly utilized for wheat dry-farming. The soils have low organic matter (about 1%) and are calcareous with a moderate value of total carbonates (Hakimi, 1986).

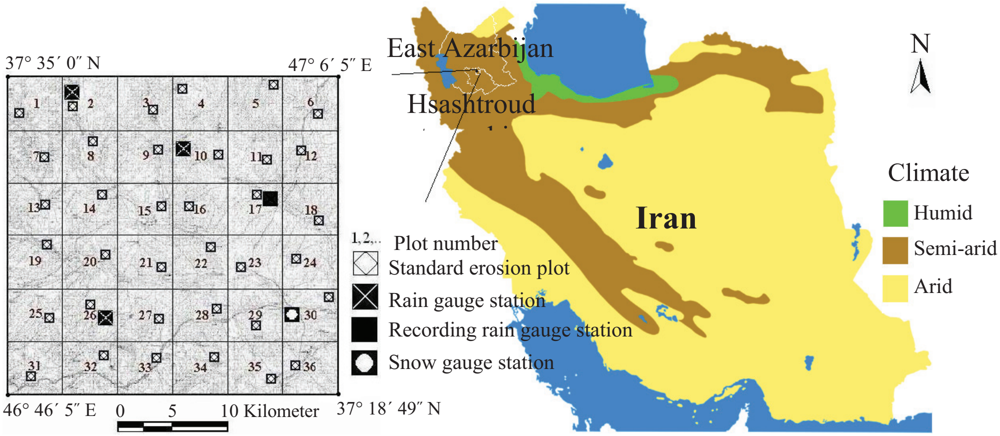

Fig. 1. Location rainfall gauge stations and unit plots in the study area, north west of Iran.

Determination of rainfall water use efficiency

Rainfall water use efficiency (RWUE) obtained from the ratio of crop dry matter per unit of abstracted rainfall water volume as fallowing:

$$RWUE = \frac{CDM}{ARWV} \quad (1)$$

where RWUE is the rainfall water use efficiency (kg/m^3), CDM is the crop dry matter of each plot (kg) and ARWV is the abstracted rainfall volume of each plot per year (m^3 $year^{-1}$). The abstracted rainfall volume (ARWV) was obtained by deducting the runoff volume (m^3) from the rainfall volume per year (m^3 $year^{-1}$)

Determination of wheat yield. Wheat grain yield was determined at 108 plots installed in 36 dry farming lands in the study area. Spring wheat was sown in about 200 m^2 area at three plots in each land right after plowing in March 2005. The size of each plot was 22.1 m length by 1.83 m width with a buffer bed 1.2 m wide in between the plots. The Sardary variety, normally grown for bread, was planted in depth of about 4-6 cm, with a 20-cm row spacing and 5-cm plant spacing. For providing similar conditions between the crop plots and erosional plots (Wischmeier and Smith, 1978), fertilizer application was avoided. Length of growing period of the spring wheat was about four months and on July 25, the crop was harvested for determining grain yield. Plant samples were randomly taken from three 1 m^2 areas of each plot by clipping the plants at the soil surface and accordingly mean grain yield of each plot was computed. Mean grain yield of each dry-farming land (t ha^{-1}) was calculated from averaging the yield values of each plot. The mean wheat yield for the 2-year study period was computed based on the yield values of the first and second year (t ha^{-1} yr^{-1}).

Measurement of surface runoff volume. Surface runoff was measured at the lower parts of the erosional unit plots. Three unit plots with 1.83 m width and 22.1 m length (Wischmeier and Smith, 1978) and 1.2 m spacing were installed beside the crop plots in each dry-farming land at the same time with the crop plots installation. The higher sides of each plot were surrounded by 30 cm ridges and its lower side, as noted by Welderufael et al., (2008) was equipped with a galvanized iron sheet protruding 30cm above the soil surface and inserted about 20 cm deep into the soil. Runoff-collecting installations consisted of gutter pipes, pipes and 70 liter tanks established at the lower parts of the plots. After each natural rainfall producing runoff at each plot, total runoff volume generated in the collecting tank was measured. Runoff was then stirred thoroughly and a 0.5 kg sample was taken to determination of water mass after subtracting the mass of the sediment. In the laboratory, the runoff samples were weighed and evaporated on a hot plate then weighed again to determine sediment concentration (Guy, 1975) and accordingly water mass was calculated. Water loss of each plot was determined based on multiplying total runoff volume of the tank by mass percentage of water in the sample. Annual surface runoff was also computed from summation of total surface runoffs produced in different natural rainfall events for each year. Runoff coefficient (runoff factor) of each plot was also obtained from proportion of runoff depth (mm) per unit of rainfall depth (mm).

Determination of rainfall volume. Rainfall volume (m^3) was calculated from multiplying the rainfall depth (m) and plot size (1.83 m×22.1m). Rainfall data were taken from five rainfall gauges stations located in the study area (Fig. 1). Four standard rainfall gauges located in the grids 2, 10, 27 and 30 were used to manually measure the depth of rain after each runoff event at the plots. An automatic rain gauge belonging to Irrigation Office of Hashtroud located in the grid 17 was also used to determine intensity of rainfall events. Rainfall data was also used to determine spatial variations of the rainfalls in the study area.

Determination of soil properties

Soil physicochemical properties were determined to identify those properties, which influence the rainfall water use efficiency. Soil samples (0-30 cm depth) were taken randomly from three locations within each plot before plowing and mixed together to provide a representative sample. After drying, the soil samples were grounded to pass through a 2 mm sieve and stored in sealed polyethylene bags in a cool and dry place until the chemical analysis was done in the laboratory. The particle size distribution (coarse sand: 0.1-2 mm; very fine sand: 0.05-0.1 mm; silt: 0.002-0.05 mm and clay: < 0.002 mm) was determined by the Robinson's pipette method (SSEW, 1982). Gravel (2-8 mm) was determined using the weighting method (Gee and Bauder, 1980). The total soil organic carbon was measured by the Walkley–Black wet dichromate oxidation method (Nelson and Somers, 1982) and converted to organic matter by multiplying it with 1.724. To determine lime amount, the total neutralizing value (TNV) on the basis of calcium carbonate was measured using acid acetic volume consumed to neutralizing carbonates (Goh et al., 1993). The available potassium content was also measured with the ammonium acetate extraction method (Knudsen et al., 1982). The aggregate stability was determined using the wet-sieving method based on the mean weight diameter (MWD) as proposed by Angers and Mehuys (1993). The water-stable aggregates were determined by placing 100 g aggregates with diameter larger than six mm on the top of sieves set and moved up to down in a water cylinder for one minute. Soil infiltration rate was determined by measuring the one-dimensional water flow into the soil per unit time by double-ring infiltrometer (Bouwer, H. 1986) at four to six replications in the plots.

Statistical analysis

Soil properties data were assessed for normality using the Kolmogorov-Smirnov test before analysis. Soil properties influencing the rainfall water use efficiency was extracted based on bivariate correlation matrix built between it and soil properties using Pearson's method.

3. RESULTS

Abstracted rainfall water volume (ARWV)

Ninety seven rainfall events occurred in the study area during the 2-year study period. Annual rainfall depth in the first and second study year was 249.3 mm and 159.5 mm, respectively. Twenty three and eighteen rainfall events produced runoff at the plots in the first and second year, respectively. There was no significant difference among the rainfall depth values in different rain gauge stations (F = 0.027, P-value = 0.994).

Mean annual surface runoff varied from 137.2 lit to 482.1 lit with an average of 327.2 lit during 2-year study period. Runoff coefficient of the plots ranged from 0.006 mm mm^{-1} to 0.031 mm mm^{-1} with an average of 0.021 mm mm^{-1}. Mean annual abstracted rainfall volume (ARWV) in 36 dry farming lands varied from 1924.9 m^3 ha^{-1} to 2010.1 m^3 ha^{-1} with an average of 1963.2 m^3 ha^{-1}. Table 1 shows mean annual abstracted rainfall volume (ARWV) in 36 dry farming lands.

Table 1. Mean annual abstracted rainfall volume (ARWV) in 36 dry farming lands

Land No.	ARVW (m^3 ha^{-1})	Land No.	ARVW (m^3 ha^{-1})	Land No.	ARVW (m^3 ha^{-1})
1	1950.21	13	1944.609	25	1940.546
2	1949.003	14	1949.227	26	1978.137
3	1952.679	15	1943.807	27	1994.81
4	1955.942	16	1997.952	28	1933.474
5	1930.262	17	1984.019	29	1952.87
6	2002.034	18	1948.958	30	1957.537
7	1974.7	19	1944.434	31	1977.34
8	1989.695	20	1970.689	32	2010.145
9	1939.323	21	1978.348	33	1975.336
10	1935.645	22	1978.417	34	1972.041
11	1924.852	23	1956.661	35	1962.749
12	1984.168	24	1970.89	36	1962.123

Soil properties

Spatial distribution of the rainfalls was uniform, as there was no significant difference in rainfall depth among the rain gauge stations. Thus, difference in the ARWV directly depended on the soil properties. The soil textures were mainly clay loam having 36.7% sand, 31.6% silt and 32.0% clay. Soils had low organic matter (1.1%) and were calcareous (limy) containing 13% equivalent calcium carbonate (lime). Mean values of gravel and potassium were 10% and 315 mg.kg^{-1}, respectively. The water-aggregate stability of the soils was very low with the mean weight diameter (MWD) value between 0.27 and 1.91 mm. The soil infiltration capacity (basic infiltration rate) varied between 1.4 and 5.8 cm h^{-1} with an average of 3.5 cm h^{-1}.

Wheat grain yield

Mean annual wheat grain yield ranged from 801.4 kg ha^{-1} to 3484.3 kg ha^{-1} with an average of 1937.8 kg ha^{-1}. Table 2 shows mean annual wheat grain yield in 36 dry farming lands. Difference of the yield among dry-lands was due to variations of soil properties.

Table 2. Mean annual wheat grain yield in 36 dry farming lands in the study area

Land No.	Wheat grain yield (kg ha^{-1})	Land No.	Wheat grain yield (kg ha^{-1})	Land No.	Wheat grain yield (kg ha^{-1})
1	801.4	13	1559.0	25	1376.3
2	1125.4	14	2118.6	26	2970.3
3	834.6	15	1445.4	27	3476.5
4	2540.3	16	3263.7	28	1187.5
5	1130.3	17	3396.0	29	1846.7
6	2641. 7	18	1724.3	30	1202.7
7	1256.7	19	1234.5	31	2340.8
8	3484.3	20	2443.3	32	3316.4
9	1265.743	21	3470.9	33	1484.5
10	1176.9	22	1757.8	34	2174.4
11	1364.5	23	1017.8	35	1446.6
12	3017.7	24	1543.7	36	1323.2

Relationship between the RWUE and soil properties

The RWUE values were between 0.35 kg m^{-3} and 1.49 kg m^{-3} with a mean of 0.84 kg m^{-3} for a 2-year study period. Table 3 shows mean annual RWUE in 36 dry farming lands in the study area.

Table 3. Mean annual Rainfall water use efficiency (RWUE) in 36 dry farming lands

Land No.	RWUE ($kg\ m^{-3}$)	Land No.	RWUE ($kg\ m^{-3}$)	Land No.	RWUE ($kg\ m^{-3}$)
1	0.35	13	0.68	25	0.60
2	0.49	14	0.92	26	1.28
3	0.36	15	0.63	27	1.48
4	1.10	16	1.39	28	0.52
5	0.50	17	1.46	29	0.80
6	1.12	18	0.75	30	0.52
7	0.54	19	0.54	31	1.01
8	1.49	20	1.05	32	1.40
9	0.56	21	1.49	33	0.64
10	0.52	22	0.76	34	0.94
11	0.60	23	0.44	35	0.63
12	1.29	24	0.67	36	0.57

The RWUE was significantly correlated with coarse sand ($r = 0.49$, $p < 0.01$), very fine sand ($r = -0.38$, $p < 0.05$), silt ($r = -0.63$, $p < 0.001$), clay ($r = 0.52$, $p < 0.01$), organic matter ($r = 0.68$, $p < 0.001$), lime ($r = 0.31$, $p < 0.05$), aggregate stability ($r = 0.60$, $p < 0.001$) and infiltration capacity ($r = 0.68$, $p < 0.001$). Infiltration capacity had the highest correlation with the RWUE because of its direct influence on the runoff generation. This result is in accord with Gómez et al. (2001), who found that approximately 50% of variability of runoff in fallow plots could be explained by the final infiltration rate. The stepwise multiple regression analysis of the RWUE and independent soil properties showed that the RWUE was significantly ($R^2 = 0.82$, $p<0.001$) related to silt, organic matter and lime (Table 4).

Table 4. The multiple regression analysis between RWUE and some soil properties

Model variable	Unstandardized coefficients		Standardized coefficient	t-level	P-level
	Model coefficients	Standard error			
Constant	613	0.188		3.256	$p < 0.01$
Silt	-.0.030	0.004	-0.578	-7.752	$p < 0.001$
Organic matter	0.762	0.106	0.527	7.160	$p < 0.001$
Lime	0.027	0.005	0.380	5.231	$p < 0.001$

Soil properties considerably enhanced the aggregate stability and soil permeability, consequently increased the RWUE. Organic matter and lime contrary to silt positively affected on the aggregate stability and soil permeability and increased the RWUE. Organic matter has been recognized as important binding and bridging agent in enhancing a soil's structural stability, infiltration capacity, and in consequence reducing runoff (Hartanto et al., 2003; Zhang et al., 2007). The result also revealed that lime is an important factor controlling runoff in soils of semi-arid study area due to the binding action of Ca^{2+} cation on soil particles, which improved the aggregates stability (Pepper and Morrissey, 1985).

REFERENCES

Angers, D.A. and Mehuys G.R., 1993. Aggregate stability to water. In: Cartner, M.R. (Editor), Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, Canada pp. 651-657.

Bouwer H. 1986. Intake rate: Cylinder infiltrometer. In: Klutem A., Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Second addition, Agronomy, Soil Science Society of America, Inc., Madison, Wisconsin, USA, pp. 341-345.

Gee, G.W. and Bauder, J.W., 1980. Particle-size analysis. In: Klutem A., Methods of Soil analysis, Part 1, Physical and Mineralogical Methods, Second eddition, AGRONOMY, Soil Science Society of America, Inc., Madison, Wisconsin, USA.

Ghawi, I. and Battikhi, A., 1986. Water melon production under mulch and trickle irrigation in the Jordan valley. Journal of Agronomy and Crop Science 157, 145–155.

Goh, T.B., Arnaud, R.J.St., and Mermut, A.R., 1993. Aggregate stability to water. In: Cartner, M.R. (Ed.), Soil sampling and methods of analysis, Canadian Society of Soil Science. Lewis Publishers, Boca Raton, Canada.

Gómez, J.A., Nearing, M.A., Giráldez, J.V. and Alberts, E.E., 2001. Analysis of sources of variability of runoff volume in a 40 plot experiment using a numerical model, J. Hydrol. 248(1-4), 183-197.

Guy, H.P., 1975. Laboratory procedures of sediment measurement techniques. In: Anoni, V.A. (Ed.), Sedimentation Engineering, Am. Soc. Civil Eng., New York, NY, USA.

Hakimi, A., 1986. The briefly study of soil science in Hashtrood. Soil and Water Research Institute, Agriculture Ministry, Iran, Research Report 767, 2-15. (In Persian)

Hartanto, H., Prabhu, R., Widayat, A.S.E. and Asdak, C., 2003. Factors affecting runoff and soil erosion: plot-level soil loss monitoring for assessing sustainability of forest management. Forest Ecology and Management, 180(4), 361–374.

Knudsen, D., Peterson, G.A. and Pratt, P.F., 1982. Lithium, sodium and potassium. pp. 225-246. In: A. L. Page et al. (Editors) Methods of soil analysis: Part 2. Chemical and microbiological properties. ASA Monograph Number 9.

Nelson, D.W. and Sommer, L.E., 1982. Total carbon, organic carbon, and organic matter. In: A.L. Page (ed.) Methods of Soil Analysis, 2nd Ed. ASA Monogr. 9(2). Amer. Soc. Agron. Madison, WI.

Pepper, R.G. and Morrissey, J.G., 1985. Soil properties affecting runoff. J. Hydrol. 79(3-4: 301-310.

Schwab, G.O., Fangmeier, D.D., Elliot, W.J. and Frevert, R.K., 1993. Soil and water conservation engineering. John Wiley & Sons, Inc., New York.

Welderufael, W.A., Le Roux, P.A.L. and Hensley, M., 2008. Quantifying rainfall–runoff relationships on the Dera Calcic Fluvic Regosol ecotope in Ethiopia. Agricultural Water Management 95, 1223 – 1232.

Wischmeier, W.H. and Smith, D.D., 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agriculture Handbook, No. 537. US Department of Agriculture, Washington DC. USA.

Zhang, G.S., Chan, K.Y., Oates, A., Heenan, D.P. and Huang, G.B., 2007. Relationship between soil structure and runoff/soil loss after 24 years of conservation tillage, Soil Till. Res. 92, 122–128.