

NOTE

SOIL WATER REGIME AND WATER CONSERVATION EFFICIENCY IN A NON-IRRIGATED SEMI-ARID ENVIRONMENT

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(Received: June 5, 2000)

ABSTRACT

Soil water content at different soil depths over time, was studied in a non-irrigated, semi-arid environment. The research was carried out for two consecutive years with below- and above-average annual rainfall, beginning in October 1996 and ending in October 1998, under cultivated and fallow conditions. For the below-average rainfall season, soil moisture content at various depths fluctuated during rainy period but returned to the initial levels by the end of the season. For the season with above- average rainfall, the final soil moisture content showed a slight increase over that at the year's beginning. Also, agricultural effective rainfall was investigated as a function of individual rainfall events for every month of the rainy season. The results showed good correlations for November through January, but weak correlations for February through April due to increased temperature and higher evaporation rates. Fallow efficiencies in rain water conservation were calculated as 4.4 and 16.2% for the below and the above

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average rainfall seasons respectively, and fallow (cultivated) efficiencies for the above situations were 0.7 and 9.5%, respectively. It was concluded that land fallowing for moisture conservation is not justified in the study area. Actually, individual rain events were only effective in providing short term (monthly) soil moisture storage. Furthermore, since arid and semi-arid environments have a variety of microclimatic situations, a thorough evaluation of soil moisture storage over time should be conducted in each specific region.

KEY WORDS: Agricultural effective rainfall, Dryland agriculture, Fallow efficiency, Soil water behavior.

تحقیقات کشاورزی ایران

۲۰: ۸۲-۹۶ (۱۳۸۰)

رژیم رطوبتی خاک و بازده ذخیره سازی رطوبت در یک محیط

نیمه خشک دیم

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به ترتیب استادیار و دانشیار بخش آبیاری دانشکده کشاورزی دانشگاه شیراز، شیراز و استادیار بخش آبیاری دانشکده کشاورزی دانشگاه فردوسی مشهد، مشهد، جمهوری اسلامی ایران.

چکیده

رژیم رطوبتی خاک، بر مبنای میزان آب قابل ذخیره در طول سال، برای اعماق مختلف در یک محیط نیمه خشک دیم مطالعه شد. در این تحقیق، رفتار رطوبتی خاک برای دو سال متوالی با بارندگی های سالانه کمتر و بیشتر از میانگین چند ساله، و شرایط آیش و کشت بررسی شد.

بر اساس نتایج حاصله، در وضعیت بارندگی کمتر از میانگین، رطوبت موجود در عمق های مختلف خاک در پایان فصل زراعی شرایطی همانند با وضعیت آغاز فصل داشت، که نشانگر ناپیچ بودن امکان ذخیره سازی آب باران در خاک است. در وضعیت بارندگی بیش از میانگین رطوبت موجود در خاک در پایان فصل زراعی فقط اندکی نسبت به شرایط در آغاز فصل تغییر کرد. همچنین در این مطالعه باران مؤثر زراعی به شکل تابعی از وقایع بارندگی برای هر ماه بررسی شد. تجزیه های انجام شده فقط برای ماه های نوامبر تا دسامبر از لحاظ آماری معنی دار بود. اما برای ماه های ژانویه تا آوریل روابط معنی داری بدست نیامد که می تواند ناشی از افزایش دمای محیط و ازدیاد تبخیر باشد. بازده آیش به ترتیب، معادل $4/4$ و $16/2$ ٪ برای سال های با بارندگی های کمتر و بیشتر از میانگین محاسبه شد. از سویی دیگر، بازده غیر آیش (کشت) برای شرایط فوق به ترتیب 7 و $9/5$ ٪ بود. چنین نتیجه گیری شد که آیش قرار دادن زمین قابل توجه نیست. بنابراین، هر گونه برنامه ریزی جهت دیمکاری با توجه به رطوبت ذخیره شده سالانه، منطقی به نظر نمی رسد. در عمل، وقایع انفرادی بارندگی با توزیع زمانی و مکانی خاص خود نقش اصلی را در تأمین رطوبت کوتاه مدت دارند. همچنین با توجه به تنوع اقلیمی حاکم بر مناطق خشک و نیمه خشک، ارزیابی وضعیت ذخیره سازی رطوبت برای هر منطقه باید بطور جداگانه انجام شود.

INTRODUCTION

Semi-arid regions, while identified as having a mean annual rainfall in the range of 250-500 mm, are still characterized by a variety of agroclimatic influences.

Geographic location, spatial and temporal distribution of rainfall, variations in solar radiation, as well as temperature, humidity and evaporation variabilities, make every region a unique environment (9). Such climatic features, as well as soil's nature and properties for water retention and redistribution, control short- and long-term behavior of soil moisture storage. As a result, prior to any dryland agricultural planning, time behavior of soil moisture storage should be studied.

Among those mentioned above, rainfall and evaporation are more directly involved with soil moisture storage in the soil profile, in many of the semi-arid environments.

Three conditions are necessary for the occurrence of evaporation (13). First of all, a continual heat supply should be available as required by the latent heat demand (590 cal g^{-1} for evaporating water at 15°C). Such amount of heat can come from within the body of soil, from outside radiation, or from advected energy. Second, there must be a positive vapor pressure gradient between the soil body and the atmosphere.

These two conditions, supply of energy and vapor removal, mostly external to the evaporating body, are influenced by factors such as air temperature, humidity, wind velocity, and radiation; labeled as the atmospheric evaporativity. The third condition necessary for evaporation to continue is the ability of water to move from or through the soil body to the evaporation site.

Under arid conditions the atmospheric evaporativity can be satisfied rather quickly. So the evaporation process is mainly governed by the evaporative ability of the soil body (6, 10, 19). However, such a process is curtailed by sharply lowered soil hydraulic conductivity due to a decrease of soil moisture over time. The net result is the convergence of soil water towards a minimum value, i.e., retention of minimum moisture.

A number of studies have focused on better understanding of the soil evaporation process. For a physical description of water loss from the soil system, the term "desorptivity" was defined as a measure of the ability of soil to lose water through evaporation (17, 18). Later, the concept of desorptivity was applied to study water loss during the constant and falling rate of evaporation (3). The effect of soil texture of bare soil surface on cumulative evaporation was studied, and it was reported that finer soil texture is likely to have more evaporation due to higher transmissivity (12).

The above studies are concerned with the understanding of the evaporation process. However, any realistic dryland agricultural planning still requires an evaluation of the actual amount of moisture stored in the soil profile over time. The term "effective rainfall" or "agricultural effective

rainfall" has been used to define and evaluate that portion of the rainfall which is stored in the root zone for plant use (4, 5, 8, 16). In this case, one may establish statistical relationships between rainfall events and agricultural effective rainfall, for a specified time period. Then, an estimation of agricultural effective rainfall (stored soil moisture) is made possible from rainfall depth. While infiltrated rain may increase the amount of soil water on a short-term basis, long-term storage of this source of moisture requires further investigation.

It is a common practice in dryland agriculture to fallow the land for one season in order to conserve rainwater for the next crop (11). However, such a storage of water is site-specific and needs to be investigated locally. Furthermore, fallow efficiency, a measure of percentage of moisture retained in the soil for a fallowed land over a specific time period, should be evaluated to justify keeping a land fallow. Actually, fallow efficiency is the net percentage increase of depth of moisture within a specified depth of soil, for a given time period. Some studies have recommended land fallowing in semi-arid environments due to cool climatic condition (2, 7). However, for a semi-arid environment with warm summer (southern California), under improved infiltration, a low fallow efficiency of 17% was reported (15). The authors concluded that land fallowing would not be feasible in this case. Certainly one could mention other main uses of fallowed land, i.e., pest and disease control, or helping with the process of nitrogen mineralization, that (if necessary) should be practiced.

The objectives of this paper are to study soil water fluctuations at different soil depths on a monthly and annual basis, to investigate the effect of fallowing land on rain-water conservation, and to evaluate the possible relationships between rainfall events and agricultural effective rainfall for the Agricultural Experimental Station of Shiraz University at Bajgah.

MATERIALS AND METHODS

Study Site

The study site is located at the Agricultural Experiment Station of Shiraz University (Bajgah). The site is characterized as semi-arid with a

mean annual rainfall of 410 mm. The study period was for two consecutive years (1996-97 and 1997-98). Annual rainfall depths were 290 mm and 541 mm, respectively, so that the effect of below- and above-average rainfall could be studied. For the study area, one rainy season exists which starts in early November and ends by late April. Previous studies place the soil of the study site in the Daneshkadeh Series (1). This series is characterized as flat with a moderate to imperfect drainage. Soil texture is clay loam (0-54 cm), clay (54-112 cm) and silty clay loam (112-158 cm). Information on field capacity (FC) and permanent wilting point (PWP) parameters for each depth is provided in the results section.

Experimental Setup

Two basins with almost no slope were prepared within the site location. Basin dimensions were selected as 8 by 8 meters. While the natural environment for rainfall infiltration was maintained, site boundaries were prepared to contain runoff. Aluminum pipes were installed at two locations in each basin for neutron probe (Troxler-Model 2651) readings up to a depth of 150 cm. One basin remained fallow during the study period, while the other one was cultivated with wheat so that a comparison of fallow and cultivated land use could become possible. Weed control was done manually.

Data Collection and Analysis

Data collection for soil moisture status was started on October 23, 1996 and ended on October 19, 1998. Soil moisture readings were done at a two-week interval, for every 15 cm depth. Data from the neutron probe readings were transformed into volumetric soil water content by applying the locally calibrated relationship. With data collection at two-week intervals and two readings for each basin, in some cases up to 12 sample points were obtained. For example if readings could be done on the 1st, 15th, and 29th, with two readings at each basin, the sample size of 6 was possible. Then, over a two-year period it would sum up to 12.

For every two-week interval between soil moisture readings, the change in volumetric soil moisture was used to evaluate equivalent depth of water for each 15 cm of soil. These values were summed over the 150 cm

soil depth, representing agricultural effective rainfall. Daily rainfall depths were obtained from the meteorological station located near the study site. Rainfall and calculated agricultural effective rainfall values were grouped for each two-week interval for further analyses.

Data analysis were done by using the STATGRAPHICS package for the purpose of establishing meaningful regression types of relationships between rainfall events and agricultural effective rainfall, on a monthly basis. Different linear and non-linear relationships were tested by setting agricultural effective rainfall as the dependent variable, and individual rainfall events as the independent variable. The analyses were carried out for each rainy month of the year.

RESULTS

Based on the analysis, the results are presented in terms of time variation of soil water, fallow and non-fallow (cultivated) efficiencies and statistical relationships between agricultural effective rainfall and rainfall depth.

Soil water behavior is presented schematically in terms of monthly rainfall variability and also the field capacity and wilting point values for each 15 cm depth of soil.

Tables 1 and 2 present field capacity (at 0.333 atmospheric pressure), permanent wilting point (at 15 atmospheric pressure), and volumetric soil moisture content at the start of cultivation season (end of October), for each 15 cm of soil depth, for fallow and cultivated conditions. Table 3 presents the equivalent soil water depth over 150-cm soil profile at the start of the cultivation season, and also fallow and non-fallow (cultivated) efficiencies. Figs. 1 and 2 present time variation of monthly rainfall and volumetric soil water content, starting on October 23, 1996 and ending on October 19, 1998 for fallow and cultivated conditions, respectively. The top portion of the figure indicates variation of soil moisture for 15-cm depths to a depth of 75 cm. The bottom portion of the figures shows the variation of soil moisture for depths of 75 to 150 cm.

Table 1. Field capacity, wilting point, and soil moisture at the start of cultivation season (fallow condition).

Soil depth (cm)	FC(%) [†]	SM1(%)	SM2(%)	SM3(%)	PWP(%)
0-15	31.7	6.4	7.0	7.91	18.0
15-30	33.1	11.0	10.6	12.3	18.6
30-45	32.9	20.5	21.1	24.6	17.6
45-60	32.7	26.2	26.3	28.3	17.5
60-75	33.6	26.0	28.6	28.6	18.5
75-90	33.5	24.3	29.7	30.7	17.3
90-105	29.6	24.2	26.2	31.1	15.8
105-120	31.3	23.1	24.3	30.0	16.0
120-135	33.4	22.5	24.3	30.0	15.6
135-150	35.3	20.5	21.1	32.7	18.8

† FC = Field capacity, PWP = Permanent wilting point, SM1, SM2, and SM3 = Soil moisture values at the start of cultivation season, for October 23, 1996, October 21, 1997, and October 19, 1998, respectively, on percent volume basis.

Table 2. Field capacity, wilting point, and soil moisture at the start of cultivation season (cultivated condition).

Soil depth (cm)	FC(%) [†]	SM1(%)	SM2(%)	SM3(%)	PWP(%)
0-15	30.9	5.5	5.6	6.0	17.2
15-30	32.3	9.8	9.6	11.7	19.0
30-45	30.3	14.9	19.7	20.2	17.3
45-60	31.1	22.5	23.8	24.3	17.4
60-75	32.5	25.4	24.2	25.8	18.7
75-90	34.5	26.2	24.8	24.8	18.5
90-105	31.8	25.5	24.2	25.9	16.6
105-120	29.3	24.5	22.2	26.3	15.4
120-135	32.9	22.8	21.9	26.7	15.3
135-150	34.9	21.7	21.1	26.3	16.8

† FC = Field capacity, PWP=Permanent wilting point, SM1, SM2, and SM3= Soil moisture values at the start of cultivation season, for October 23, 1996, October 21, 1997, and October 19, 1998, respectively, on percent volume basis.

For the purpose of establishing statistical relationships between rainfall depths and agricultural effective rainfall, linear and non-linear relationships were tested. The best results were provided by a simple linear relationship as follows:

Table 3. Efficiency of soil water conservation under fallow and cultivated conditions, in the top 150 cm of soil.

	Fallow condition	Cultivated condition
October 23, 1996 DSW [†] (cm):	30.7	29.8
October 21, 1997 DSW (cm):	32.1	29.6
1996-97 fallow efficiency(%):	4.4	---
1996-97 non-fallow efficiency(%):	---	-0.7
October 21, 1997 DSW (cm):	32.1	29.6
October 19, 1998 DSW (cm):	38.3	32.7
1997-98 fallow efficiency(%):	16.2	---
1997-98 non-fallow efficiency(%):	---	9.5

† DSW = Depth of soil water at the start of cultivation season.

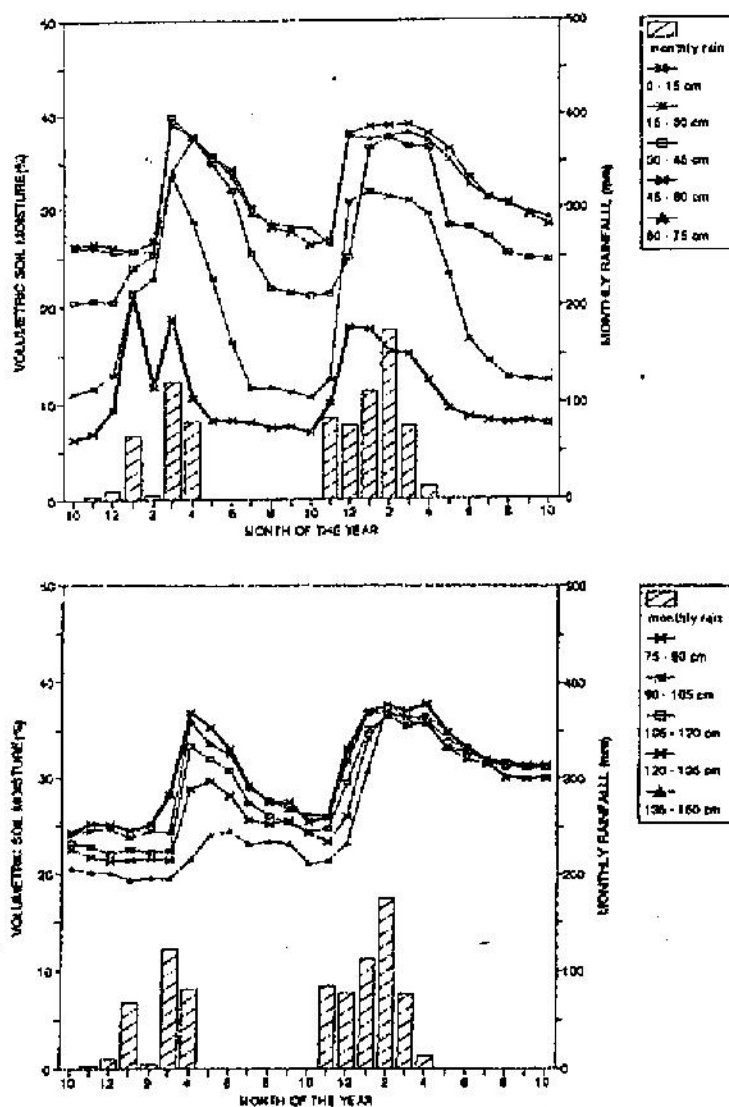


Fig. 1. Long-term volumetric soil moisture variations under fallow condition.

$$AEF = b_0 + b_1 R$$

[1]

where AEF is agricultural effective rainfall (change in soil water depth) due to a rainfall event in a given month (mm) and R is depth of a rainfall (mm) event in a given month. Table 4 shows numerical values of b_0 and b_1 , as well as related statistical information. Due to lack of rain events during October (for the study period), no relationships were provided.

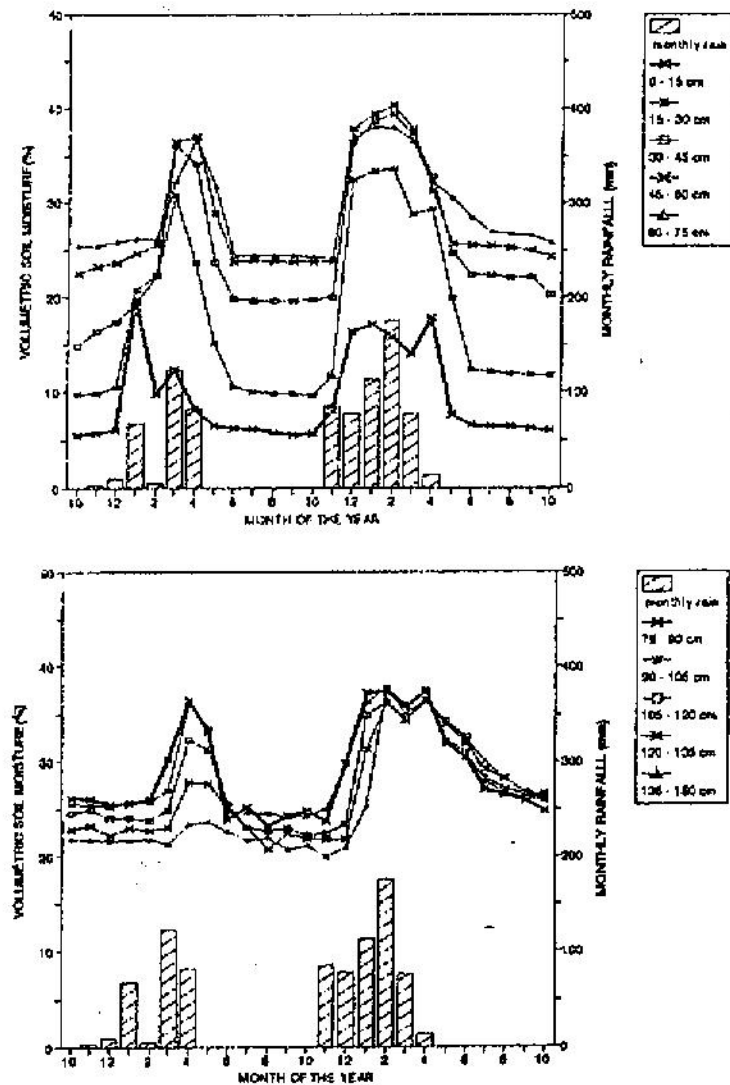


Fig. 2. Long-term volumetric soil moisture variations under cultivated condition.

Table 4. Statistical parameters of linear regression.

Month	Land condition	Regression coefficients		R^2	n^{\dagger}	P
		b_0	b_1			
November	F [†]	-1.26	0.127	0.596	8	0.025
November	C	-1.58	0.152	0.583	8	0.027
December	F	0.39	0.123	0.765	10	0.000
December	C	0.51	0.106	0.772	10	0.000
January	F	-0.70	0.524	0.831	8	0.002
January	C	0.12	0.603	0.946	8	0.000
February	F	-0.49	0.003	0.100	8	0.948
February	C	-1.24	-0.024	0.400	8	0.636
March	F	13.80	0.129	0.282	6	0.278
March	C	13.40	-0.110	0.526	6	0.103
April	F	-2.57	0.200	0.128	12	0.253
April	C	-4.20	0.162	0.066	12	0.422

† F = Fallow, C = Cultivated.

§ n = Sample size, P = Statistical level of significance.

DISCUSSION

This study focused on time behavior of soil moisture at different soil depths as influenced by evaporation demand and rainfall events. The idea was to study the influence of evaporation demand on preservation of soil water and also to investigate the impact of rainfall events on storage and redistribution of soil moisture over time. Based on the results the following points are discussed:

1. Tables 1 and 2 represent values on PWP, FC and start of cultivation season SM1, SM2, SM3, for fallow and cultivated sites. A comparison of FC and PWP values for the two sites show a small variation which is mainly attributed to soil spatial variability as well as computational errors. Soil moisture conservation at the end of the first year (SM2) is minimal, returning to the year's starting values (SM1). Soil moisture conservation at the end of the second year (SM3) has a small positive value in comparison with that at the year's beginning (SM2) due to the above average annual rainfall.
2. Based on the results (Tables 1 and 2), soil moisture contents for depths of (0-15) cm and (15-30) cm were below PWP for the study period, regardless of the previous year's rainfall situation, or type of land use. This would indicate that for the study area, fallowing the land would not lead to an increase in soil moisture, specially for the upper soil layer

where moisture is needed for seed germination. It is noted that for the above average annual rainfall situation, the moisture content for depths of more than 30 cm shows an increase, even getting close to field capacity values in some cases. However, this moisture is not available in the upper depths during the seed germination stage.

3. Table 3 presents rainwater conservation efficiencies for the below-and the above-average rainfall situations. Fallow efficiencies were computed as 4.4 and 16.2%, while non-fallow (cultivated) efficiencies were 0.7 and 9.5%, respectively, for the two consecutive years. Increase in non-fallow efficiency for the second year indicates the possibility of moisture not being consumed by plants. There is no documentation on the established criteria for minimum stored soil moisture to justify land fallowing. However, a study in the northwestern area of the USA showed the possibility of at least 20% increase in annual soil moisture, which is used as a justification for land fallowing in that region (14). Then for the present research, the values on fallow efficiencies do not support the idea of fallowing the land as a practice for rainwater conservation in the study area. In a similar study conducted in semi-arid southern California, a fallow efficiency of 17% with improved infiltration was reported (15). The authors did not recommend land fallowing under the conditions of their study. One may conclude that individual rainfall event with appropriate temporal and spatial variations play a major role in providing short-term moisture. The effect of rainfall events on redistribution of soil water leading to a short-term increase of moisture at various soil depths, are also shown by Figs. 1 and 2.
4. The regression relationship of Eq.[1] would be best representative if developed on a monthly, rather than seasonal basis. In this region, as a result of monthly variations in rainfall depth, stored soil water goes through major fluctuations. Then any seasonal relationship would not be all that realistic. Also in Eq. [1], AEF is the change in soil water depth between two rainfall events, then any monthly soil moisture carry over would be minimal. Relationships between agricultural effective rainfall and rainfall depth may be used to predict/estimate soil moisture

availability on a short-term basis. However, as indicated by the results, this approach is not always applicable, specially for the warmer months of the year. This is particularly true from February on with generally weaker correlation values, due to the increase in temperature as the controlling factor of soil moisture status. As a result, a meaningful relationship between agricultural effective rainfall and rainfall is not always possible. Therefore, unless the influence of increased temperature is studied in more details, use of agricultural effective rainfall versus rainfall relationships should be limited to the colder months.

ACKNOWLEDGEMENTS

The authors wish to thank the Research Council of Shiraz University for providing financial support (Project 1374-AG-932-543).

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