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Rainfed farming prospects in the low rainfall zone of northern Iraq based on meteorological and soil moisture measurements

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ABSTRACT

More than 50% of the rainfed region in Northern Iraq falls within the low rainfall zone receiving between 300 and 400 mm of mean seasonal rainfall. Several natural runoff plots with access tubes were used to measure soil moisture distribution in depth and time. Measurements during two consecutive rainfall seasons were used to forecast the rainfed farming prospects in the low rainfall zone. The first season is considered wet because it received 568 mm of mean seasonal rainfall; the second rainfall season is considered dry because it received 256 of mean seasonal rainfall. The prospects of tillage systems, fertilization, and soil moisture conservation for a successful rainfed farming (wheat and barley crops) venture in the low rainfall zone were explored, and a rainfed farming guide for this zone was suggested.

KEY WORDS: Iraq, Mediterranean climate, rainfed farming, rainfall distribution, soil moisture

INTRODUCTION

Rainfed farming will continue to play an important role in providing food and livelihoods for an increasing world population. There is a little room for further expansion of large-scale irrigation due to the world water crisis. The challenge for improvement of rainfed farming is concentrated in the world semiarid and subhumid climate regions where rainfed farming is the dominant source of livelihood and where water availability limits crop production. In these regions, long-term crop yield under rainfed condition can be improved with improved soil, water, nutrient, and crop management.

The rainfed farming region in Northern Iraq comprises a total area of more than five million ha of forest, grazing land, and farm land areas located to the north of the 300 mm mean seasonal rainfall isohyet. The region is often divided into three zones according to the mean seasonal rainfall. The high rainfall zone receives more than 600 mm of mean seasonal rainfall; the medium rainfall zone receives between 400 and 600 mm of mean seasonal rainfall; the low rainfall zone receives between 300 and 400 mm of mean seasonal rainfall. This last zone occupies more than 50% of the rainfed farming region in the country; rainfed farming in this zone is more risky than the other two zones due mainly to the low mean seasonal rainfall.

The region has a semi-arid Mediterranean type climate; in this climate, efficient precipitation capture and storage are necessary for successful small grains (wheat and barley) production giving that the winter precipitation occurs before the stages of most active growth and grain development (William and Wuest, 2014). Tillage system used in the region is normally conventional tillage. Studies have shown (Patrignani *et al*., 2012) that this type of tillage is linked with the low precipitation storage efficiency and contributes to water and wind erosion. Vegetation water stress is related to soil moisture and the length of time soil moisture is below a given threshold (Manfreda *et al*., 2010). Time series of soil moisture level during the rainfall season for the low rainfall zone was studied by Hussein *et al*. (2005).

The purpose of this study was to use available meteorological and soil moisture data at the experimental site to assess the potential of rainfed farming success in the low rainfall zone of northern Iraq. Ecological and social issues should also be considered for a sustainable rainfed farming system (ICARDA, 2013).

MATERIALS AND METHODS

Several natural runoff plots were established in March 1988 on a uniform slope area of 6% gradient, located at the experimental farm of the College of Agriculture and Forestry-Mosul University in Hammam Al-Ali (36°10′N, 43°20′E). Plot design and installation were done according to the procedure outlined by Mutchler (1963). Access tubes for soil moisture measurement were installed on all plots. The site was equipped with a nonrecording rain gauge during the 1987-1988 and 1988-1989 rainfall seasons.

The experimental site was used primarily as grazing land ad its soil is classified as fine, mixed, thermic, calcareous, xerroloic calciorthid. General soil characteristics are given in Table 1. Mica and chlorite are the dominant clay minerals followed by kaolinite and montmorillonite.

The region has a semi-arid Mediterranean type climate. Wet cold winter and a dry hot summer characterize it. Rainfall season in the region normally extends from October to May. Mean seasonal rainfall at the site is about 330 mm with moderate season to season variability (Hussein *et al*., 2005). Rainfall shows wide fluctuation, in the rainfall distribution during the season, duration of the rainy season and rainfall intensity. Table 2 gives mean monthly values of air temperature, pan A evaporation, rainfall, relative humidity, and wind speed at the experimental site.

Each autumn, and after rain showers had moistened the soil, the plots were tilled by spading and left in the fallow condition throughout the rainfall season. Herbicides were used to control weeds. During the first (wet) rainfall season (1987-1988), soil moisture measurements were delayed until the plot establishment was completed in early March 1988; excessive rainfall during that season prevented normal field work. Soil moisture measurements at a 0.1 m depth interval were made on a biweekly basis by using the neutron probe method. If rain occurred on or shortly before a measurement date, measurement was delayed until the moisture of surface soil dropped to a level that permits normal field work, and this usually occurs within 1-3 days after the rainfall event. During the second (dry) rainfall season (1988-1989), soil moisture measurements started on the first of October and continued on a biweekly basis until the first of July. A greenhouse experiment for the Saber Beg wheat variety (*Triticum aestivum* L.) indicated a wilting point soil moisture levels of 0.3 field capacity (FC) (FC, soil water content after the saturated soil has drained under gravity to equilibrium) and 0.5 FC at seedling (Wp1) and maturing (Wp2) stages, respectively.

Three replicated plots, 30 m × 3 m in size were selected for this analysis. Soil profile depth at the lower end of plots was 1.2 m and decreases in the upslope direction

Table 1: Soil characteristics at the experimental site

Depth (m)	Particle size distribution (%)			Organic matter (%)	Bulk density (mg/m^3)	Saturated cond. (mm/h)	Soil moisture (V/V) at	
	Clay	Silt	Sand				0.033	1.5 MPa
≤0.3	36	44	20	1.5	1.3	37	0.30	0.09
0.3-0.7	43	34	23	0.5	1.4	28	-	-
0.7-1.2	50	34	16	-*	1.5	17	-	-

*-Not recorded

Table 2: Recorded mean monthly values of some meteorological variables at the experimental site (after Hussein, 2001)*

Month	Mean air temperature (°C)	Mean Pan A evaporation (mm)	Mean rainfall (mm)	Mean relative humidity (%)	Mean wind speed at 2 m (km/h)
January	6.9	33	58	82	3.4
February	8.5	70	51	81	3.5
March	12.1	100	61	75	4.3
April	16.9	133	41	67	4.1
May	23.3	272	12	46	4.6
June	28.9	418	1	32	4.8
July	33.1	542	0	30	5.3
August	32.7	517	0	32	5
September	28	340	0	42	4.3
October	21.3	185	9	55	4.2
November	12.9	77	44	70	3.4
December	7.9	34	58	84	3

*Recording period 1967-1990

to a depth of about 0.6 m at the upper end of plots. The plots have three excess tubes each located at the upper, middle, and lower parts of the plot.

RESULTS AND DISCUSSION

Rainfall Distribution at the Experimental Site

Figure 1 shows the distribution of monthly rainfall during the wet and the dry rainfall seasons. The wet rainfall season (total seasonal rainfall = 568 mm) shows a continuous monthly rainfall distribution with the highest monthly rainfall depth occurred during the month of January. On the other hand, the dry rainfall season (total seasonal rainfall = 256 mm) shows a discontinuous monthly rainfall distribution due to a zero total monthly rainfall during the month of April; the highest monthly rainfall depth occurred during the month of March.

In semiarid and subhumid areas, it is not the amount of rainfall that is the limiting factor for crop production, rather it is the extreme variability of rainfall with high rainfall intensities, few rain events and poor spatial and temporal distribution of rainfall. Hence, rainfall is both a critical input and a primary source of risk and uncertainty regarding production outcomes in rainfed areas.

Soil Moisture Distribution During the Rainfall Season

Figures 2 and 3 show that soil moisture during the rainfall season is above the wilting point for the specified crop (Saber Beg wheat variety) in both deep and shallow soils. After heavy showers, soil moisture level may exceed the FC for a day or two during which significant percolation may occur (Hussein, 2001). Figure 2 shows that during the dry rainfall season, low temperature (Table 2) keeps soil moisture at an optimum level for plant growth throughout most of the growing season.

Maximum soil moisture level occurs during the months of January and February where the soil moisture is near the FC level (Figures 2 and 3). Figures 2 and 3 also show that surface soil moisture gradually diminishes during the hot summer due to the dry weather condition and high temperature and it reaches a level near the wilting point for seed germination and seedling (Wp_1) for the plant just before the start of rainfall season. This suggests that early season showers are necessary for optimum soil moisture for conventional seedbed preparation. The optimum soil moisture is generally at 0.1 bar suction since at lower suctions, soil aeration tends to be a problem in fine textured soils. Suctions above 1 bar generally reduce crop yield especially if occurred during the critical stages

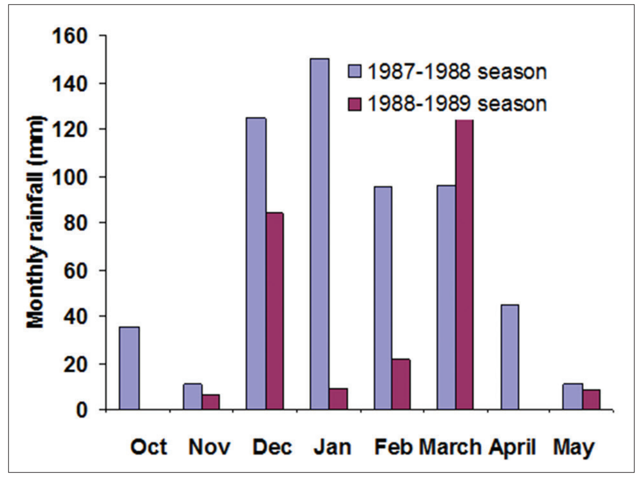

Figure 1: Distribution of monthly rainfall during the wet (87-88) and the dry (88-89) rainfall seasons

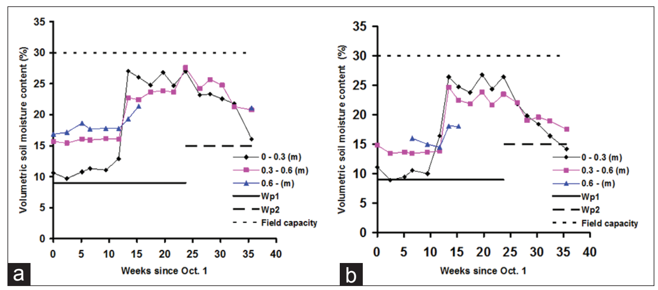

Figure 2: Soil moisture time series during the dry (88-89) rainfall season: (a) Soil profile depth = 1.2 m; (b) soil profile depth = 0.7 m. Average of three replicates

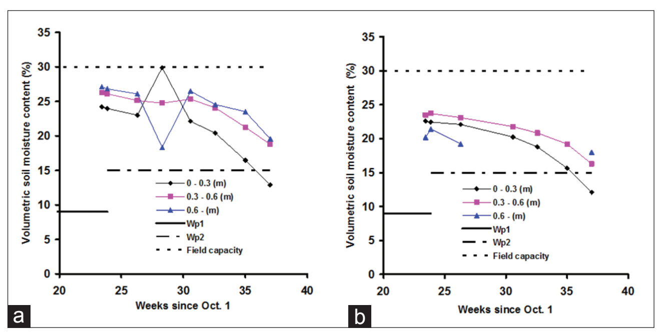

Figure 3: Soil moisture time series during the wet (87-88) rainfall season: (a) Soil profile depth =1.2 m; (b) soil profile depth = 0.7 m. Average of three replicates

of flowering and seed formation. In Figures 2 and 3, intra-annual soil moisture change decreases as soil depth increases due mainly to the decreasing effect of evaporation on soil moisture as soil depth increases; this results in a decrease in inter-annual soil moisture changes as soil depth increases with such change nearly disappears at soil depth of several meters (Wang *et al.*, 2016).

Soil moisture storage at the experimental site during the rainfall season approximates a normal probability distribution; the slight to moderate left skew observed is caused mainly by low soil moisture storage values occurred at the beginning and/or at the end of the rainfall season (Hussein *et al*., 2005).

Rainfed Farming in the Low Rainfall Zone

As mentioned earlier, the region has a semi-arid Mediterranean type climate. The period of plant active growth is the months of March and April. The most suitable crops are the early maturing grains such as wheat and barley (Al-Fakhry, 1979). Small grains such as wheat and barley are grown more in rainfed farming areas because they grow during cool weather and thereby use water more efficiently and produce some grain even under relatively dry conditions. Subfreezing temperature may occur during the period December through February. Rain in the region starts in early or mid fall and ends in mid or late spring. Problems with rain in the region include the delay in fall rain which affects seeding time and seedlings, the limited usefulness of rain in the cold period because of slow growth, and the insufficiency of spring rain necessary for a high and economic yield. In recent decades, the Mediterranean region suffered from a more arid climate condition with an increase in mean air temperature, reduction in total seasonal precipitation and higher intensity and frequency of extreme weather events (Pedro *et al*., 2015); this results in yield losses in long cycle winter crops such as wheat and barely. Flowering and seed formation are the most critical periods in plant life where moisture is greatly needed followed by germination and seedling stages which affect plant growth in the later stages.

During the 1988-1989 rainfall season, soil moisture in the surface soil stayed below 0.15 V/V through much of the fall season (Figure 2). Such moisture level is held in the soil at about 12 bar suction. During the winter, minimum daily temperature dropped frequently below the freezing point. Therefore, a proper germination for small grains used in the region was not possible (Ahmed, 1987). For this reason, rainfed farming during this season was risky and uneconomical. In general, if the fall rain is sufficient and the crop is planted no later than November, the crop will grow successfully throughout the growing season. However, crop failure due to drought could probably be prevented through improved farm-level water management.

Most crops currently grown in the region are surface rooted. The root system concentrates in the upper 25 cm of the soil. Figures 2 and 3 indicate that 0.5 FC moisture level in the surface soil is reached before the first of June. Hence, surface rooted crops may be harvested no later than the first half of June.

Seeding depth and rate as well as distance between rows depend on the crop grown. Population density must be restricted where soil moisture is limited or all plants will suffer moisture stress. Wheat, other small grains and sorgum often counteract low seeding rates by tillering profusely under favorable conditions. Thus, wheat yield may not greatly different whether seeded at rates of 35 or 85 kg/ha because thin crop will tiller to fill the space. Howver, if too much seeds is used, the plants compete for water and space so that no individual plant grows well. In extreme cases, water is insufficient to bring the crop to maturity. A thinner stand under the same low moisture regime may survive and produce a harvestable crop (Troeh *et al*., 2004).

Rainfed farming has traditionally been managed at the field scale. Supplemental irrigation systems provide water during periods when rainfall is insufficient to provide essential soil moisture to secure harvest. Supplemental irrigation can bridge critical dry spells and stabilize yield in most semiarid and subhumid regions. *In situ* water harvesting (i.e., the capture of local rainfall on farmland) for supplemental irrigation use may be affordable to most smallholder farmers. In arid regions, the improvement in crop yield due to supplemental irrigation use can be substantial (Oweis, 1997).

The current tillage practices used in the region are mostly moldboard plowing and disking for seedbed preparation. Due to the low soil organic matter content, deep and frequent tillage cause a speedy soil moisture loss. Since tillage must start after rain has moistened the soil, delay in rainfall will cause a delay in germination that significantly affect the crop stand. No-till planting in November may guarantee a relatively high crop yield if the rainfall season is not dry. A locally tested conservation tillage system should be tried in the region for a better-rainfed farming venture. Local studies (Abdullah, 2014; Alrijabo *et al*., 2014; Mikha *et al*., 2013) indicated a soil moisture storage improvement during dry rainfall seasons when conservation tillage is used. However, other studies in the region indicate the benefit of moldboard plowing and disking in increasing the crop yield compared to chisel plow (Al-Tahan and Rajabow, 1989); this yield increase was attributed to the increase in rainfall infiltration associated with the increase in surface roughness.

Fallow is sometimes practiced in the region to increase soil fertility (not for soil moisture conservation) with the fallowed area grazed by animals. Fertilization will likely increase the biological yield, but the increase in grain yield depends on soil moisture (Al-Fakry and Ali, 1989). In this case, fertilization may decrease the yield index (grain yield/biological yield) if the rain was sufficient during the vegetative growth period but below normal during the active growth period. Fertilizers (mostly N and P) are usually added at seeding time. However, the nitrogen fertilizers are better added in more than one stage to avoid a vigorous vegetative growth early in the season which may hasten the depletion of soil moisture. The second stage of nitrogen fertilization should be added when soil moisture is at its highest level for the nitrogen to move rapidly to the roots (Barber, 1976). Fertilizer overdose may reduce crop yield and hence soil test interpretation should be utilized.

Although wheat and barley are the conventional crops grown, legumes grown for food and grazing may also succeed. Broadbean, clover, and medic were grown successfully within the low rainfall zone under rainfed farming condition during normal rainfall seasons (Al-Fakhry and Sultan, 1979; Shafiq and Kedar, 1989). These legumes may be grazed if the late season rainfall is insufficient to produce an economic yield.

Soil Moisture Conservation and Water Management

In semiarid areas, up to 50% of rainfall is lost from the field as non-productive soil evaporation (Rockstrom, 2003). Reducing evaporation and enhancing rainfall infiltration are well-known methods to increase soil moisture storage. Soil moisture conservation in the field is needed during the period of crop active growth. Using crop residues is a well-known practice to conserve soil moisture. Residues reduce evaporation by increasing reflection and resistance to vapor diffusion. However, with the lack of rainfall over a long period (e.g. >1 month), soil moisture conservation by crop residues will be small unless water can be moved deep into the soil profile (Van Doren and Allmaras, 1978).

Converting some of the water to productive transpiration through evaporation management will increase water productivity in semiarid areas. Evaporation management does not directly impact local runoff, hence improving yield from rainfed farming without affecting downstream water uses and ecosystems. Options to reduce soil evaporation include dry planting, no-till and reduced tillage and mulching. Higher water productivity is also achieved by improving crop yield.

Rainfed Farming Guide for the Low Rainfall Zone

In Iraq, the current rainfed farming yield is about 20% of attainable yield which suggests a large untapped potential for yield increases. There are two broad strategies for increasing yield in rainfed agriculture when water availability in the root zone constraints crop growth: (1) Capturing more water and allowing it to infiltrate into the root zone and (2) using the available water more efficiently (increasing water productivity) by increasing the plant water uptake capacity and/or reducing non-productive soil evaporation. There is a wide spectrum of integrated land and water management options for use in achieving these aims (Rockstrom *et al.*, 2010).

The soil moisture regime on a plot grown with unfertilized wheat variety (Saber Beg) compared favorably with that on a plot in fallow (Table 3). Access tubes were installed in patches cropped with wheat and located at the middle part of the slope; access tubes on adjacent fallowed patches were also installed.

Based on the above discussion, a rainfed farming guide for the low rainfall zone was proposed (Table 4). Probability analysis showed that seasonal rainfall at the experimental site approximates a normal probability distribution (Hussein *et al.*, 2005) with a mean of 332.4 mm, standard deviation of 102.5 mm, and skewness coefficient of 0.6. The probability of rainfed farming success in dry years will likely increase if a proper land and water management scheme is adopted.

Table 3: Soil moisture under the fallow condition compared to that under common wheat (Saber Beg, *Triticum aestivum* L.) at the maturing stage made during the 1991-1992 rainfall season (total seasonal rainfall=310 mm)*

Date	Soil moisture (V/V) at depth of					
	0.05 m		0.15 m		0.25 m	
	Fallow	Cropped	Fallow	Cropped	Fallow	Cropped
25-4-1992	0.16	0.17	0.18	0.19	0.18	0.18
2-5-1992	0.15	0.15	0.17	0.17	0.17	0.18
9-5-1992	0.14	0.14	0.17	0.16	0.17	0.16

*Measurements locations were 15 m upslope from the lower end of plots, soil profile depth=0.9 m

Table 4: A proposed rainfed farming guide in the low rainfall zone of northern Iraq for small grains (wheat and barley)

Element	Recommendation
Root type	Moderately deep
Seeding time	November, December seeding may result in delayed germination
Tillage	Reduced tillage with a proper crop residues management
Harvest	Mid May to mid June
Fertilization	N, P at seeding time; additional fertilization depends on soil moisture and plant needs
Moisture conservation and water management	Evaporation management using mainly reduced tillage, crop residues will be useful giving that a proper weed control program is implemented

In semiarid regions, dry spells (short periods of drought during critical growth stages) occur almost during every rainy season. By contrast, meteorological droughts occur on average once or twice every decade. Both dry spells and meteorological droughts frequencies are predicted to increase with climate change (IPCC, 2007). Water management is useful to bridge a dry spell, but crop yield cannot be sustained during a meteorological drought.

CONCLUDING REMARKS

The following concluding remarks may be made from this study:

a. Maximum soil moisture storage during the rainfall season occurs during the months of January and February where soil moisture storage at equilibrium approaches the FC level
b. Soil moisture storage during the rainfall season approximates a normal probability distribution
c. A proper integrated land and water management scheme along with improved crop varieties suitable to the climate and soil conditions in the low rainfall zone are essential for a more successful rainfed farming venture in this zone.

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