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Impacts of different water harvesting techniques on barley productivity under semi-arid conditions in Palestine

Ahmad Y. Safi[1], Prof. Ayed G. Mohammad[2]

1: Master student, Natural resources and its sustainable management program, College of Agriculture, Hebron University.
2: Professor at College of Agriculture, Hebron University (Corresponding)

Abstract:

Water is the main limiting factor in rain-fed cropping systems under semi-arid environmental conditions, and because of the characteristics of rainfall in general, and low precipitation in particular, the productivity of plants is very low. This study was conducted at Al-Ubeidiya town in Bethlehem governorate to evaluate the effect of using water-harvesting techniques on the productivity of barley (*Hordeum valgare* L.) during two consecutive seasons. Three treatments were evaluated; namely: strip planting, ploughing-sowing-ploughing, and contour ridges, in addition to the control treatment (traditional planting method). Split-plot design was used to compare among treatments. The results showed the positive effects of water harvesting practices on barley productivity where a significant increase was obtained in grain and straw weight by 37% and 76% respectively, by using strip planting compared to the traditional cultivation (control). Grain and straw yield and plant height gave the best results in strip planting, followed by ploughing-sowing-ploughing, then the contour ridges, while the lowest values were in the traditional planting.

These results suggested that using simple and practical water harvesting techniques for barley cultivation under semi-arid conditions have the potential to increase barley grain and straw yield.

Key Words: Rainwater Harvesting Techniques, Semi-arid area, Rain-fed Agriculture, Barley cultivation.

الملخّص:

يُعدّ الماء العامل المحدّد لنجاح نموّ النباتات في الزّراعة البعليّة في المناطق شبه الجافّة؛ حيث إنّ أنماط التّساقط المطريّ عمومًا، وقلتها خصوصًا تؤدّي إلى قلّة الإنتاجيّة في هذه المناطق. و تجدر الإشارة إلى أنّه تمّ تنفيذ هذه التّجرِبة في بلدة العبيديّة في مدينة بيت لحم لتقييم تأثير استخدام تقنيات الحصاد المائيّ المختلفة على إنتاجيّة الشّعير (*Hordeum valgare* L.) خلال موسمين متتاليين، فقد أظهرت النّتائج أنّ استخدام طرق الحصاد المائيّ أدت إلى زيادة في إنتاجيّة الحبوب والقشّ بنسبة (37% و 76%) على التّوالي نتيجة استخدام تقنية strip مقارنةً بالطريقة التقليديّة، وكانت أوزان الحبوب والقشّ وطول نبات الشّعير أفضل في جميع طرق الحصاد المستخدمة Strip planting، ploughing-sowing-ploughing و contour ridges مقارنةً بالطريقة التقليديّة (S-P) traditional planting التي أعطت أقلّ النّتائج. إنّ استخدام طرق حصاد مائيّ بسيطة وعمليّة في المناطق شبه الجافّة لزراعة الشّعير من دوره أن يزيد إنتاجيّة الشّعير.

الكلمات المفتاحية: طرق الحصاد المائي، المناطق شبه الجافة، الزراعة البعلية، زراعة الشعير

Introduction:

Rain-fed agriculture is the traditional farming system in arid and semi-arid areas (Ammar, *et al*., 2016; Creswell, *et al*., 1998) where most countries depend primarily on this system for their grain food (Aydrous, *et al*. 2015). According to Scheierling and others (2012), 80% of cropped areas in the world depend on rainfall alone. Shortage of water, low and uneven distribution of precipitation are major challenges faced by farmers who rely on rain-fed farming (Chen, *et al*., 2019; Ammar, *et al*., 2016; Creswell, *et al*., 1998), which makes rain-fed agriculture a risky enterprise (Aydrous, *et al*. 2015). Plant production in rain-fed agriculture could be reduced by up to 50% in some regions by 2020 (Field, *et al*., 2014). Devendra (2016) indicated that if the rain fails there will be a reduction of feed availability for grazing animals. Tilahun, *et al*., (2011) found that the productivity of field crops under rain-fed conditions is far less than that under irrigation. The low yield of field crops in rain-fed farming is due to various reasons; such as low rainfall, poor soil moisture, large variability of rainfall both within and between seasons, low soil nutrients content, and lack of weed control (Turk and Tawaha, 2003; Al-Tawaha *et al*., 2003).

However, in many semi-arid areas, tropical and arid regions, as well as in some temperate regions the crop production is relatively low, therefore, water management is suggested to be the key for improving agricultural production in these lands (Scheierling, *et al*., 2012).

Irrigation is not possible in large areas of Asia, and rain-fed agriculture remains a major contributor to agriculture production (Devendra, 2016). Water harvesting techniques (WHTs) is one option that can increase the amount of water per unit cropping area, reduces drought effects, and enables use of runoff beneficially (Zhang and Oweis *et al*., 1999). In addition, Li and others (2019) indicated that rainwater harvesting system has huge attention worldwide.

Oweis and Hachum (2009) stated that the principle of WHT is based on the concept of depriving part of the land of its share of precipitation which is usually small, non-productive and giving it to another part to increase the amount of water available to the latter part. While Critchly and Sigert (1991) defined WHT as collection of runoff for its productive use.

Water harvesting systems were established in many parts of the world for thousands of years. Contour terracing was used in the central highlands of Mexico 1000 years ago (UNEP (1983); water harvesting structures in Jordan, have been constructed for 9000 years (Prinz, 1996); and run-off-irrigation systems have been found in the semi-arid to arid Negev desert region for 5000 years (Evenari *et al*., 1971).

Water harvesting technique has become an effective way to fight against droughts for arid and semi-arid regions (Zhang, *et al*., 2007). According to Rebeka (2006), rainwater-harvesting techniques can be applicable in all agro climatic zones. However, it is more in arid and semi-arid areas where the average annual rainfall is from 200 to 400 mm (Mohammad, 2008). In addition, water harvesting technique is a promising practice for increasing water storage in soil, improving soil organic carbon and finally increasing plant productivity in semi-arid areas (Deng *et al*. 2019; Wang *et al*. 2018).

AL-Tawaha, *et al*. (2018) found that barley plants grown under water harvesting techniques (WHT) provide higher yield compared to those plants which were grown without WHT. On the other hand, Adgo, *et al*. (2013) indicated that soil and water conservation increased crop productivity, they found that barley productivity was 950 kg/ha in terraced fields compared with control areas where barley productivity was 490 kg/ha.

According to the National Agricultural Sector Strategy (2017-2022) Resilience and Sustainable Development (2016) the rain-fed farming in Palestine represents an important component of the agriculture production system and it occupies 81% of total area of land used for agriculture. In Palestine, field crops are mainly rain-fed, their cultivation and production has decreased in recent years due to fluctuations in rainfall quantities, low profitability per dunum, high production cost, and weak resistance to diseases.

Since agriculture production of rain-fed farming in the semi-arid regions is very dependent on rainfall and its distribution, water harvesting might be an effective way to improve field crops productivity in semi-arid areas and decrease drought effect. In semi-arid areas, yield of rain-fed crops can be improved by increase water availability to the crops, maximize water holding capacity of the soils, and improve plant water uptake capacity (Beernaerts, 2003), and by providing more balanced soil moisture during the growing season through water harvesting techniques (Mohammad, 2008; Alseekh and Mohammad, 2009). The aim of this study is to evaluate the effects of different water harvesting techniques on barley yield under semi-arid conditions.

Methodology

This experiment was conducted in Al-Ubeidiya town in Bethlehem Governorate. The site is located 8.4 km East of Bethlehem City and 10 km Southeast Jerusalem (latitude 31°42'8.77"N and longitude 35°17'4.64"E). Al-Ubeidiya located at an altitude of 532 m above sea level with a mean annual rainfall of 246 mm (ARIJ GIS, 2009). The average annual temperature is 18.5 C^{o}, and the average annual humidity is about 58 percent (ARIJ GIS, 2009). The soil at the study site is brown randzin, and soil type is clay loam with a 15% slope (MoA, 2011). This area was used to evaluate the effect of different WHTs on barley production (grain weight, straw production, and height of the barley plants). Qenare 6 rows of barley were planted (12 kg/dunum) on the 6th of December for year 2012/2013 and on 10th of December for year 2013/2014 in the following treatments: 3 water harvesting techniques namely Strip Cropping (SC), Contour Lines (CL), and Ploughing-Sowing-Ploughing (PSP) in addition to the traditional method as a control (Sowing-Ploughing (SP)) where barley seeds are sown and then ploughed by animals. Each treatment was repeated three times (the area of each replicate was 650 m^2), split plot design was used to compare between treatments, where the years as the main plot and the water harvesting techniques the sub-plot.

Treatments:

- **Strip Cropping (SC):** Tilling strips of land along crop rows (1.5 m cultivated) and leaving appropriate sections (1 m) of the inter-row space uncultivated to release runoff.

- **Contour Lines (CL):** The contour lines (ridge and furrow) had been established by using animals, and then barley seeds were sown inside the furrows.

- **Ploughing-Sowing-Ploughing (P-S-P):** The soil was ploughed during early October, then when a sufficient amount of rainfall had fallen (at least 10 mm precipitation), the barley seeds were sown then some tillage was practiced mainly to cover the seeds.

- **Traditional Method (Sowing – Ploughing (SP)):** This treatment was used to compare with the other treatments and was considered as a control, which represented the local method of barley planting in Al-Ubeidiya village where the barley seeds were broad casted then some tillage was practiced mainly to cover the seeds.

All treatments were fertilized by 20 Kg/dunum with triple super phosphate ($Ca(H_2Po_4)$ fertilizer which broadcasted before sowing as traditionally practiced by the farmers in the area.

The barley samples and measurements were collected for all treatments on the 6th of June of each study year. Ten 0.25 m² square quadrates were allocated randomly in each replicate in all treatments. In each quadrate, every part of the plant was collected and placed in labeled paper bags. The air-dried weight of the grain and straw were measured separately. Barley production (grain and straw) was determined directly as weight g/0.25 m^2, then the data were converted into Kg/dunum.

In the field, the heights of 10 randomly chosen plants were measured in each replicate for all treatments.

-Results:

The experimental site received 262.0 mm and 280.8 mm annual rainfall in 2012/2013 and 2013/2014, respectively (Fig. 1). The variability in the amount of rainfall between the years is a normal character of rainfall in such an arid and semi-arid region that has also become more clear as a result of the climate change. Although the amount of rainfall in year 2013/2014 was higher than that in year 2012/2013 but it was relatively more evenly distributed in year 2012/2013 than in year 2013/2014. In 2012/2013 most of the rainfall was extended from November to February, on the other hand in 2013/2014 it was during December and March. Rain gauge did not record any amount of rain during January.

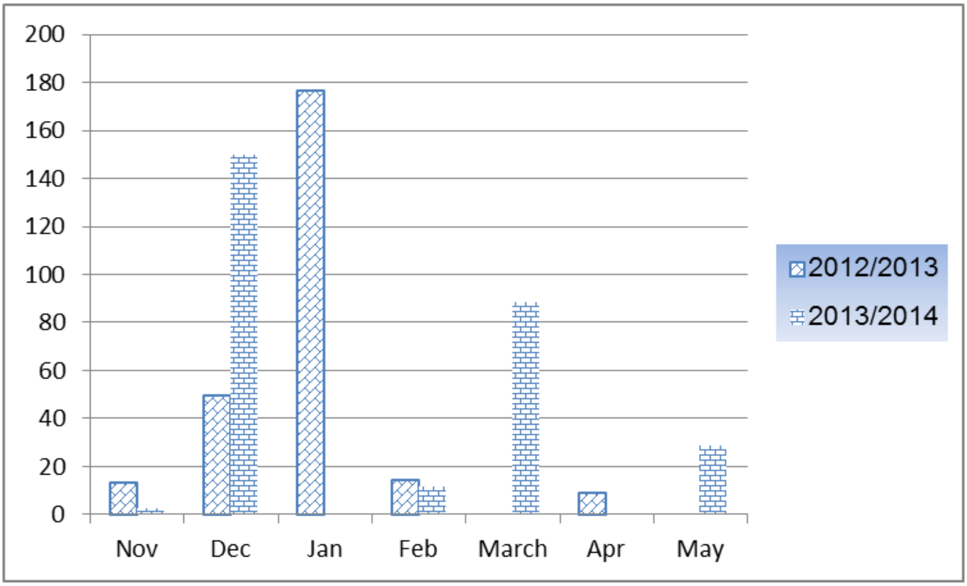

Figure 1 Monthly Rainfall at Al-Ubeidiya site during 2012/2013, 2013/2014

- **Grain Weight:**

The data in table (1) showed that water-harvesting techniques, when averaged over the years, gave a higher grain weight (yield) than the traditional planting method with a significant ($p \leq 0.05$) average increase by 37.3, 33.5 and 37.5 kg/dunum by using the strip, contour lines, and ploughing-sowing-ploughing methods respectively, compared with the traditional method. Data showed no significant difference between the water harvesting treatments. As for the interaction between years and planting methods (table 1), only contour lines during the first year gave significantly higher grain weight (150.7 kg/dunum) than the traditional method (101.4 kg/dunum). Although other treatment combinations gave higher yield but not significantly different from the traditional method.

- **Straw Weight:**

Straw weight was significantly increased by applying water harvesting technique (table 1) when data averaged over the years. Strip method showed the highest straw weight (358.8 kg/dunum)

which is significantly higher than other treatments, while the traditional method gave the lowest straw weight (204.3 kg/dunum) which is 43% lower than the strip method.

Table (1) Average barely grain weight (Kg/Dunum), straw weight (Kg/Dunum) and plant height (cm/plant) in Al-Ubeidiya during 2012/2013 (year 1) and 2013/2014 (year 2) study years.

	Grain Weight (kg/dun)			
	Strip	Contour lines	P-S-P	Traditional
Year 1	148.1ab*	150.7a	135.7ab	101.4b
Year 2	129.3ab	119.1ab	142.1ab	101.3b
Average	138.7A**	134.9A	138.9A	101.4B
	Straw Weight (kg/dun)			
Year 1	352.4a	271.9bc	295.3abc	184.8d
Year 2	365.1a	279.4abc	331.6ab	223.8cd
Average	358.8A	275.7B	313.5B	204.3C
	Plant Height (cm)			
Year 1	55.9a	47.8ab	48.9ab	44.6ab
Year 2	45.7ab	40.7bc	40.1bc	28.1c
Average	50.8A	44.3B	44.5B	36.4C

* Means of the treatment interaction for each variable followed by the same lower case letter are not significantly different, according to Tukey's test at P ≤0.05.

** Means of the split plot treatments averaged over years for each variable followed by the same upper case letter are not significantly different, according to Tukey's test at P ≤0.05.

The results showed high significant differences (P≤0.05) for the interaction between years and planting methods (table 1). The strip method recorded the highest value in the two study years followed by P-S-P and contour lines. The traditional method recorded the lowest values in the two study years (184.8 kg/dunum in 2012/2013 and 223.8 kg/dunum in 2013/2014).

- **Plant Height:**

The data in table (1) showed a significant (P≤0.05) interaction between years and planting methods on plant height. Strip method in 2012/2013 recorded the highest average plant height (55.9 cm/plant) followed by P-S-P in 2012/2013 (48.9 cm/plant) and contour lines (47.8cm/plant) during the same year while the traditional method recorded the lowest value (28.1 cm/plant). On the other hand, the plant height increased significantly (P≤0.05) by 17.6 cm, 12.6 cm and 12 cm by using the strip, contour lines and ploughing-sowing-ploughing methods respectively, compared with the traditional method.

However, the data in table (1) showed that strip method over years gave the highest average plant height (50.8 cm/plant) followed by P-S-P (44.5 cm/plant) and contour lines (44.2 cm/plant) while the traditional method gave the lowest height (36.3 cm/plant). The strip method increased plant height significantly (P≤0.05) compared with contour ridges and traditional method, otherwise the strip method gave no significant difference (p ≥ 0.05) when compared with P-S-P treatment.

Discussion:

Using the traditional method may not help to conserve enough water for barley production; high-intensity rain events lead to an increase in water runoff and soil erosion. Barley growth conditions may further be hampered by a number of climatic factors; low and erratic rainfall, low relative humidity levels, and high temperature during the growing season. There are several options to improve barley production at the southern parts of West Bank, one of these options is the use of Water harvesting techniques (WHTs). Oweis and Hachum, (2009) said that field crop yield in the cropped area with WHTs should be at least twice that purely rain-fed area without using any water harvesting technique.

Results showed that WHTs (Strip planting, P-S-P, and contour lines) have significant effect on grain weight, straw weight and plant height compared with the traditional method (tables 1). Generally, these results provide a promising possibility of increasing the barley productivity under hard environmental conditions by using new planting methods.

The three water harvesting techniques that were under investigation gave significantly higher grain weight, straw weight, and plant height compared to the control (traditional method), these results indicated that water harvesting techniques overcome the influence of low amount and poor distribution of rainfall on barley yield. In addition, the data showed no significant difference between these techniques for grain weight while for straw weight and plant height the strip method gave the highest value than P-S-P and contour methods. This result is consistent with Hatibu and Mahoo (1999), were they mentioned that WHTs used to enhance barely productivity through increasing the amount of water stored in the soil profile by trapping and intercepting the runoff. Also the conclusions of many studies (Al-seekh and Mohammad (2009), Karrar *et al*., (2012),Nyagumbo *et al*. (2019) and Deng *et al*. (2019)) where indicated that soil moisture retention increased when water harvesting structures were practiced; and hence crop yield also increased. Therefore, the strip, P-S-P, or contour method might increase the storing moisture in the soil profile and yet provide more moisture for barley during the growing season that make soil moisture more balanced mainly during the periods of no precipitation or in case were precipitation distribution within the season is poor since it is normal character for rainfall distribution in semi-arid conditions and during the study years also (Figure 1). In addition, Li and Gong (2002) reported that rainfall-harvesting systems, as furrow and ridges, increased water availability for crops and enhanced agriculture production in Loess Plateau in northwest China. Ngigi (2003) and Barron and Okwach (2005) concluded that poor distribution of rainfall, due to dry spells, together with low nutrient input during critical growth stages leads to low yields or crop failure.

All treatments gave higher values of grain weight, straw weight, and plant height, compared with traditional planting. These results might be attributed to effective rainfall collection when using strip, P-S-P and contour lines as water harvesting techniques. This indicates that these techniques collected a satisfactory amount of water towards meeting barley water requirement. On the other hand, the data showed a significant interaction between the water harvesting techniques and years (which represent mainly different climatic factors) where this interaction was not consistent for the variables under investigation (table 1). Because of the influence of the climatic factors mainly amount and distribution of rainfall on the efficiency of certain water harvesting technique, Hatibu and Mahoo (1999) and Zhang and Oweis *et al*., (1999) indicated that these factors should be considered in choosing the suitable water harvesting technique for certain area. Although, the current study showed a significant interaction between the WHT's and years, but still there is a need for more studies on the influence of different climatic factors on the efficiency of the different WHT's.

Our results are in agreement with those of Al-Satari *et al*., (2013) who showed the vital role of WHTs in improving barley yield in low rainfall areas. Increased plant height, tillers number of contour ridges, and strip methods in comparison with the traditional method were attributed to the effective collection of rainfall in barley plants root zones. In addition, Ali Abu-Nukta *et al*., (2009) found that plant height, barley grain and straw weight were increased by using strip cropping and ploughing opposite to the land slope. Similar results were found by Nyagumbo *et al*. (2019) where maize yields significantly higher in the water harvesting techniques compared to the standard controlled ridge.

Soil and water conservation practices have the ability to intercept rain water and enhance the soil moisture contents for crop use and minimize the soil sediment loss (Rashid *et al* 2016). Chapman and Carter (1976) indicated that the effectiveness of rainfall in promotion plant growth depended on three factors: amount of moisture, distribution of moisture, and soil texture. Our results showed that by using water harvesting techniques we can manipulate the effectiveness of rainfall on plant growth which might be through increasing soil moisture and decreasing the variation in soil moisture during the growing season.

Conclusion:

Applications of simple and practical water harvesting techniques in semi-arid areas have the potential to improve the field crops productivity. Therefore, soil and water conservation practices should be considered in rain fed agriculture.

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