WATER INNOVATION TECHNOLOGIES PROJECT (WIT)

UNDERSTANDING THE CHANGE IN IRRIGATION BEHAVIOUR

SUBMISSION DATE: SEPTEMBER 2021

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WATER INNOVATION TECHNOLOGIES PROJECT (WIT)

TASK MEL 3.4: UNDERSTANDING THE CHANGE IN IRRIGATION BEHAVIOUR

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WATER INNOVATION TECHNOLOGIES PROJECT (WIT)

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ACRONYMS

COVID-2019	Corona Virus 2019
Dunum	0.1 hectare
IWMI	International Water Management Institute
MC	Mercy Corps
PC	Pressure Compensating
USAID	US Agency for International Development
WIT	Water Innovations Technologies
WST	Water Saving Technology

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SUMMARY

Water scarcity has become a major issue during the 21st century, with more than two thirds of the world's population under water stress for at least one month of the year and half a billion people experiencing severe water shortages daily. One of the countries that is particularly affected is the Kingdom of Jordan. According to the World Resource Institute, Jordan is ranked fifth place in terms of countries suffering from water scarcity issues[1], with an annual water resource is 145 m^3 per capita[2], far lower than the United Nation's 500 m^3 threshold that indicates absolute water scarcity. This problem is getting worse due to growing population and the impact of climate change. Climate change is leading to unpredictable rainfall while increasing temperatures are causing surface water evaporation and a more arid landscape.

Water Innovations Technologies (WIT) program is a five-year (2017-2022), USAID-funded initiative designed to conserve water in Jordan by adopting proven water-saving technologies and techniques. Mercy Corps is the primary implementing partner for USAID with the International Water Management Institute (IWM)I is a sub-awardee of WIT. One of the proven water-savings technologies that WIT has introduced is improvements in drip irrigation technology with pressure compensating emitters. This technology ensures a more uniform application of water across a field irrespective of pressure variations due to elevation or due to friction in long lengths of pipe. One of IWMI's role in WIT is to develop and implement a robust system to monitor the water savings achieved through introduction of the water saving technologies and practices. In consultation and collaboration with all WIT partners, IWMI developed a cost-effective, context appropriate solution which consisted of installing analog water meters on farms where investments have been made in water savings technology. At each farm a control plot i.e., a farm plot without any investment in water savings technology was instrumented with an analog water meter and a treatment plot i.e., a farm plot with an investment in water savings technology was instrumented with an analog water meter. The difference in water applied (volumetrically per month) adjusted/normalized per unit area (per dunnum = 0.1ha) constitutes the water savings and is attributed to the water saving technology. For the periods March 2019 – February 2020 the saving was estimated at 5.201Mm^3 and from March 2020 – February 2021 the water savings is estimated at 5.837Mm^3. However much of this water saving is from an increase in the area under water savings technology. When normalized per unit of area the water savings in 2019: 464 m^3/dunum decreases in 2020 to 311 m^3/dunum.

This is counter intuitive as one would expect with experiential learning with new technology the use of the technology would improve and therefore outcomes i.e., water savings would increase.

[1] M. Wright, "Most Water-Stressed Countries in The World For 2019," CEO World Magazine, 2019. [Online]. Available: https://ceoworld.biz/2019/08/08/most-water-stressed-countries-in-the-world-for-2019/. [Accessed: 20-Sep-2021].

[2] V. Yorke, "Politics matter: Jordan's path to water security lies through political reforms and regional cooperation," 2013.

IWMI in addition to the role of developing and implementing the water savings in WIT is also the lead partner in the WIT Learning Agenda. The Learning Agenda is designed to explore/research and answer specific questions and exploit learning opportunities. Hence IWMI was tasked with answering the learning question, why have water savings decreased rather than increased over time?

This report examines this question in more depth. The apparent decrease in water savings is an artifact of the way in which WIT monitors water savings. WIT defines water saving as the difference between a control plot (without water savings technology) and a treatment plot (with water savings technology). Indeed, this is an intuitive, logical, and objective measure. However, what has happened is that farmers seem to have changed their behavior and in the second year have started to apply far less water to control plots even though these plots do not have any water innovations technology. Hence, the difference in water applied to the control plot versus treatment plot is less and therefore water savings appears to be less.

This immediately raises the question: Why did farmers in their second year reduce water applied to the control plots. This report hypothesizes that when farmers are informed of the "over-irrigation" in year 1 and its role in increasing the operational costs and the negative impact on utilizing fertilizers and water. This influences their behavior in year 2. This report tests this hypothesis and establishes that the savings in year 1 are indeed an explanatory variable for the reduction in water applied to control plots in the subsequent year. In fact, for every $1m^3$ of water savings in year 1 will lead to a reduction of $0.46m^3$ in year 2.

This has two important implications:

1. Although in WIT water meters were simply a monitoring tool, water meters or more generally credible, timely, context specific information to farmers on their irrigation practices does lead to water savings i.e., information in itself (perhaps derived from water meters) is a water savings technology.
2. The water savings as documented by WIT are an under-estimate because water savings occurred on the control plots where physical water innovations technology were not installed but as a result of the information available to farmers. The regression equations developed in this learning agenda report can be used to estimate this additional water savings.

INTRODUCTION

The Water Innovations Technologies (WIT) program is a five-year (2017-2022), USAID-funded initiative designed to conserve water in Jordan by adopting proven water-saving technologies and techniques. IWMI is a sub-awardee of the WIT Program and, as a sub-recipient of WIT, contributes to various components and activities to WIT, such as Monitoring, Evaluation, and Learning (ME&L).

The objective of the WIT Learning Agenda is to generate a learning program that will produce evidence to accompany the implementation of the project and allow progressive elaboration to continue the implementation with clear outcomes and aligned impact.

The WIT project has been running for four years and has achieved more than the planned target (18.5 MCM), The total water saved as of August 31st was 20,588,095 m^3 from the agricultural sector alone. A total of 72 farms has been monitored by August 2021 (the sample selected for this study involves only 48 farms– those with complete data sets on water application for the first two seasons). These farms are located in the Mafraq governorate and Azraq district with a total monitored area of 13,749 dunums. The water savings calculations depend on the "Farm Scale Water Accounting" method that is conducted at the plot level to derive savings per unit area. Savings per unit area are then extrapolated to the farm level, that IWMI developed and implemented in the last four years. The method involves installing analog water meters at two comparable small fields (plot level) within the farm. One of the fields is upgraded with a water innovation technology- the treatment field. The other field represents- the baseline or control plot- where conventional irrigation technology and management are implemented. IWMI collects monthly meter readings to calculate water application per unit area for the treatment and control plots. The difference in water application is the estimate of the water savings attributed to the water innovation technology. The unit area estimate is then extrapolated to the entire area in the farm that has upgraded with water-saving technologies. The Farm Scale Water Accounting method is described in (Figure 1).

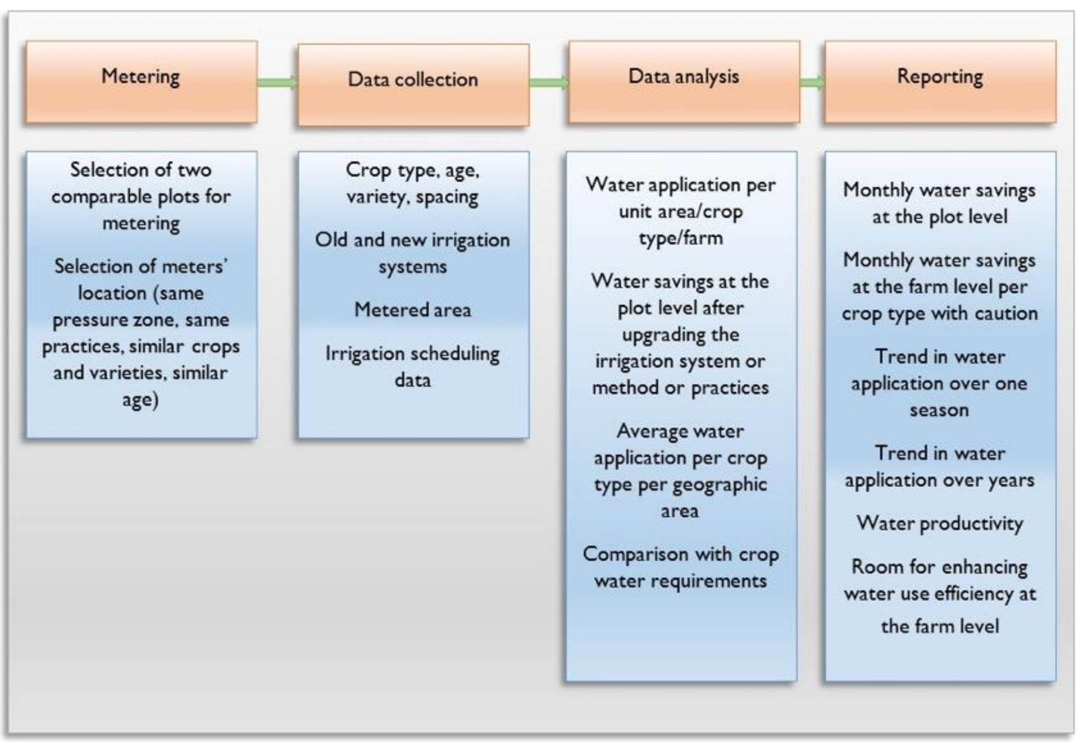

Figure 1: Farm Scale Water Accounting.

IWMI have analyzed the time-series datasets (available in the WA database that is submitted monthly to the AG team) on water application over two years (2019 & 2020) for some monitored crops and observed a decrease in the accounted water savings in 2020 relative to 2019. This was anomalous and not easily explained. Figure 2 provides a little further insight. Water savings as described in the previous paragraph is the difference in the volume of water applied to a treatment plot and a control plot. Figure 2 shows the volume of water (per unit of area) for 2 seasons[3] (2019 and 2020) for the control and treatment fields.

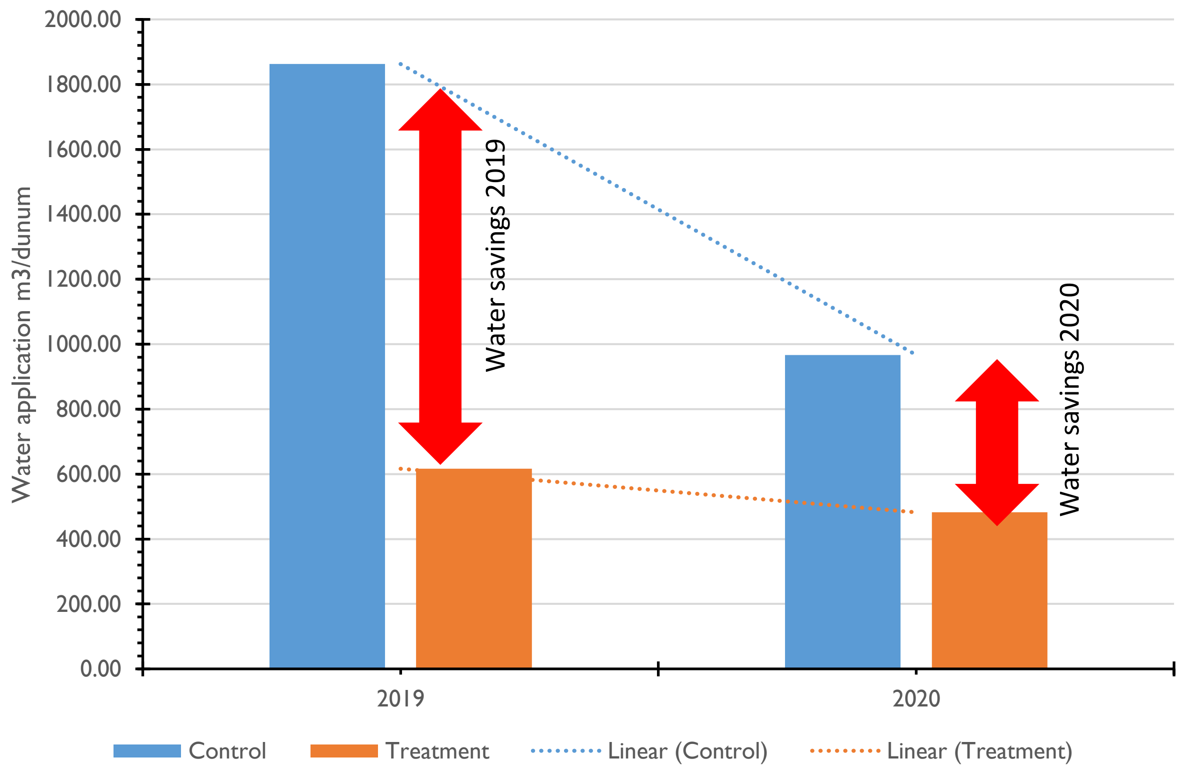

Figure 2: Water applied to treatment and control plots on stone fruits.

Figure 2 illustrates graphically the water savings (difference between control and treatment plots) has decreased from 2019 to 2020. However, what is also apparent from Figure 2 is the volume of water applied on the treatment plots has not changed significantly between 2019 and 2020. However, the volume of water on the control plots has changed significantly between 2019 and 2020. Since water savings is the difference (of volume between treatment and control fields), hence water savings has decreased between 2019 and 2020.

This however raises another question – why has the volume of water applied to control plots decreased so substantially – what explains this observed irrigation behavior? To further

[3] Each season is defined typically as the duration between March/specific year and February/the following year.

understand this observation, IWMI conducted interviews with three farmers (two from Azraq and One from Mafraq) in August 2020 to investigate any changes in their irrigation scheduling that led to less water application on control plots. The interviewed farmers confirmed that after observing meter readings on treatment plots this informed them of the irrigation amounts to apply to control plots and save water from better irrigation practices on plots still treated with old irrigation systems. The three farmers also confirmed that after observing treatment plots for one season, they noticed better crop quality and uniform fruit size.

IWMI's early observations and farmers' feedback raised a need to investigate more this topic. It represents a potential learning piece that can contribute to the overall WIT learning Agenda.

THE HYPOTHESIS

The observation described in the previous section would suggest that the meters which were installed in WIT entirely for monitoring and evaluation i.e., not as a water innovation technology– themselves are a water innovation technology that leads to water savings and learning.

It is hypothesized that a farmer who can explicitly observe volumes of water applied to a field– hitherto impossible as there is no in farm metering in Jordan– changes her/his behavior with this information.

IWMI believes that exploring and understanding this observation and quantifying the contribution of irrigation behavioral change to the observed reduction in water application on control plots would contribute significantly to report evidences to WIT management and communicate it with wider stakeholders Therefore, IWMI intends to test this hypothesis for the first two seasons after adopting water saving technologies in 48 farms where data sets on water application is complete for the two seasons.

MATERIALS AND METHODS

This task aims to understand and explain the irrigation behavior of farmers on their control plots and draw inferences about farmer behavior across various crop types and across both governorates. Specifically, what are the statistically significant explanatory variables that explain this change of behavior. This task will investigate irrigation behavioral change using econometric/statistical tools. Econometrics integrate economics, mathematical economics, and statistics intending to provide numerical values to the parameters of economic relationships.

Water application is a function of any number of factors and possibly the interaction of these factors. For the purpose of illustration of the methodology to be used we assume the volume of water applied is a function of two factors:

- Irrigation behaviour of the previous season.
- Weather conditions.

Therefore, water application can be expressed as a function of irrigation behavior and weather conditions as follows:

$$Y = f(X_1, X_2 \dots . X_N) \text{ .... (1)}$$

where Y=change in water application between one season and the preceding season; X_1= first explanatory variable e.g., difference between treatment and control plot in the preceding season; X_2= second explanatory variable e.g., weather; and X_n= n^{th} explanatory variable.

If we assume that a linear relationship is a reasonable model between the variable of interest and the explanatory variable, then (1) becomes

$$Y = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots . \beta_n X_n) \text{ .... (2)}$$

where in (2), β_i = coefficient of the ith term. For a linear equation such as above, standard statistical tools such as ordinary least squares regression or maximum likelihood can be used to estimate the coefficients and their statistical significance. Equation (1) and (2) are over-simplifications that are presented for illustration purposes only. In practice a large number of variables are considered in the model. Variables may be continuous, binary, or categorical.

IWMI will use water application data for three seasons already acquired from the monthly water accounts monitoring. This data disaggregated by different crops, including (stone fruits, olive, grape, pomegranate, and palm dates). The time-series data will be analyzed to observe the trend in water application over three seasons on treatment and control plots for different crops. The output from this activity is the average monthly and seasonal water application per unit area of treatment and control plots for dominant crops. The modelling will incorporate monthly rainfall and temperature data for the three seasons since weather is intuitively a strong explanatory variable.

The modelling will use autoregressive terms i.e., the behavior in the previous season (volumes applied and/or water savings) to explore if there is a learning process i.e., the learning from the previous season explains behavior in the subsequent season. The proposed regression models will be implemented with the existing datasets.

RESULTS AND DISCUSSION

This section is organized in three distinctive parts as follows:

1. Overall Statistical Analysis and Evaluation of Water Application on Treatment and Control Plots– Mafraq

Water application on treatment and control plots was analyzed for the four major crops monitored in Mafraq (grape, stone fruit, pomegranate, and olive). The total number of plots included in the analysis was 55, including 29 treatment plots and 26 control plots. The number of control and treatment plots was not identical because, in some farms, there is no control plot as the farmer optimized the whole area. Therefore, we included only treatment plots at these specific farms to ensure the sample size is as big as enough for sound statistical analysis (average/mean value of water application on treatment plots (See table 1- Number of treatment plots are higher than control plots as some times one control plot is used for two farms– due to the adoption of WST on the whole farm). The 55 plots were monitored by meters (water application is measured). Other plots monitored by comparison with similar farms, or where water application is estimated were excluded from the analysis.

The monthly average water application volumes for each crop type were calculated from the selected sample and aggregated to derive the seasonal water application volumes. Table 1 summarizes the duration of each season and the number of plots used to derive the average water application in each season.

TABLE 1: SEASONS AGGREGATION AND NUMBER OF MONITORED PLOTS.

SEASON	Season 1	Season 2	Season 3	Season 4
DURATION	Mar. 2018 – Feb. 2019	Mar. 2019 – Feb. 2020	Mar. 2020 – Feb. 2021	Mar. 2021 – Jul. 2021
#MONITORED PLOTS	2 control, 3 treatment (5 plots)	20 control, 23 treatment (43 plots)	25 control, 28 treatment (53 plots)	24 control, 28 treatment (52 plots)

Figures 3, 4, 5 and 6 illustrate the statistical evaluation of the analysis conducted on all control and treatment plots in Mafraq. As observed, water application was the least in the first season, mainly due to the under-representative sample size of plots monitored in that season. Similarly, water application in season four was relatively small because the dataset does not cover the entire season. The two complete data sets are for seasons two and three, further analyzed in the following sections.

Figure 3 shows that the average water application on control plots cultivated with grapes and located in Mafraq has reached a maximum of 1,440 m^3/dunum in the second season after adopting water-saving technologies. However, irrigation application decreased to 1,195 m^3/dunum in the following season, indicating the change in irrigation practices on control plots. On the contrary, average water application increased on treatment plots from 892 m^3/dunum in the second season to 1,106 m^3/dunum in the third season, with less average water savings in the third season compared to the second season.

Figure 4 shows that the average water application on control plots cultivated with stone fruits reached a maximum of 1,876 m3/dunum in the second season. Average water application decreased to 1,329 m^3/dunum in the third season, indicating a change in irrigation practices on control plots. However, water application on treatment plots increased from 718 m^3/dunum in the second season to 869 m^3/dunum in the third season, and the average water savings were fewer in the third season relative to the second season.

For plots cultivated with pomegranate (Figure 5), the average water application on control plots increased from 1,269 m^3/dunum in the second season to 1,286 m^3/dunum in the third season. However, the average water application on treatment plots decreased from 983 m^3/dunum in the second season to 888 m^3/dunum in the third. The average water savings were higher in the third season relative to the second season.

Average water application on olive control plots was the same in the second and third season, while for treatment plots, it increased from 437 m^3/dunum in the second season to 705 m^3/dunum in the third season leading to fewer savings in the third season relative to the second season.

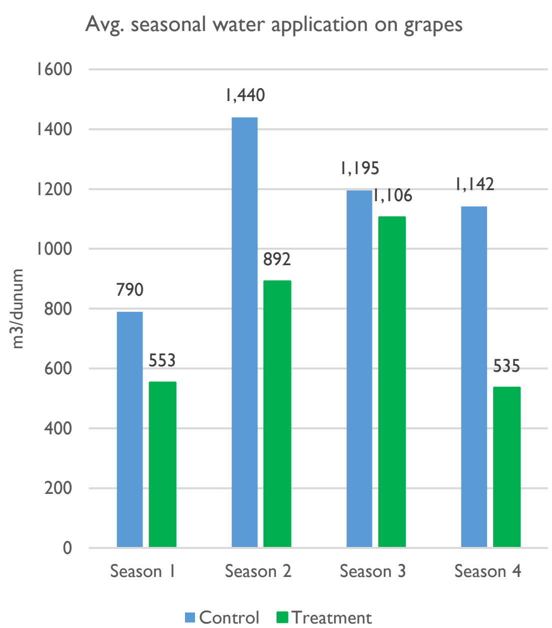

Figure 3: grapes– Mafraq.

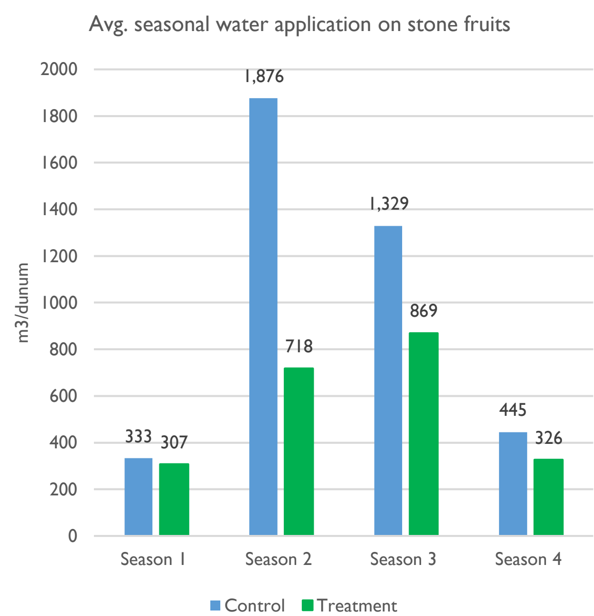

Figure 4: stone fruits – Mafraq.

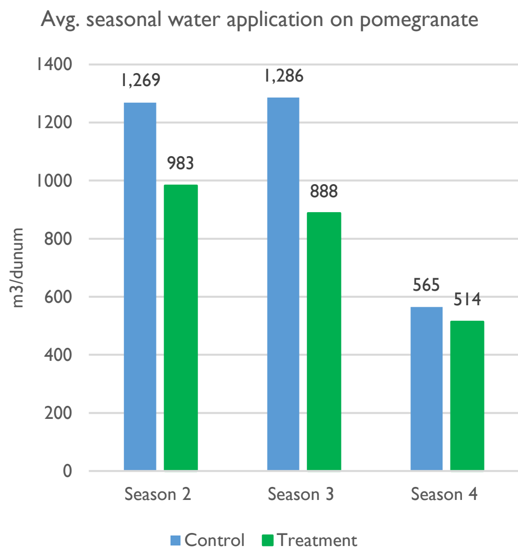

Figure 5: pomegranate– Mafraq.

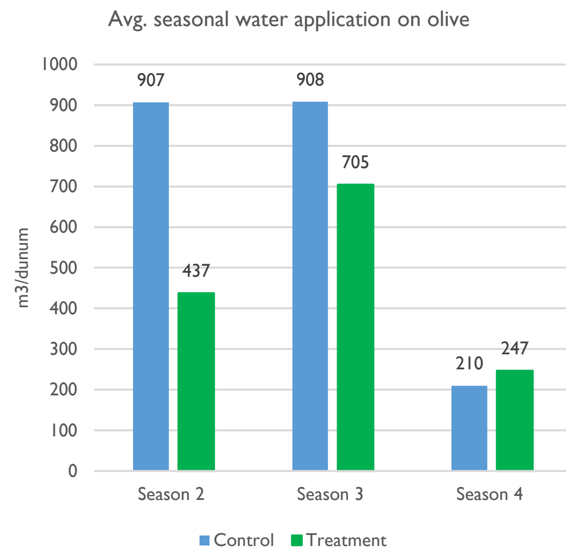

Figure 6: olive– Mafraq.

2. Overall Statistical Analysis and Evaluation of Water Application on Treatment and Control Plots– Azraq

Water application on treatment and control plots was analyzed for the four major crops monitored in Azraq (grape, pomegranate, olive, and palm dates). The total number of plots included in the analysis was 45, including 25 treatment plots and 20 control plots. The number of control and treatment plots was not identical because, in some farms, there is no control plot. Therefore, we included only treatment plots at these specific farms to ensure the sample size is as big as enough for sound statistical analysis (average/mean value of water application on treatment plots) (See table 2- Number of treatment plots are higher than control plots as some times one control plot is used for two farms– due to the adoption of WST on the whole farm). The 45 plots were monitored by meters (water application is measured). Other plots monitored by comparison with similar farms or where water application is estimated are excluded from the analysis.

The monthly average water application volumes for each crop type were calculated from the selected sample and aggregated to derive the seasonal water application volumes. Because monitoring in Azraq has started in 2019, the analysis was conducted for three seasons only. Table 2 summarizes the duration of each season and the number of sample plots used to derive the average water application in each season.

TABLE 2: SEASONS AGGREGATION AND NUMBER OF MONITORED PLOTS.

SEASON	Season 2	Season 3	Season 4
DURATION	Apr. 2019– Mar. 2020	Apr. 2020– Mar. 2021	Apr. 2021– Jul. 2021
#MONITORED PLOTS	15 control, 19 treatment (34 plots)	20 control, 25 treatment (45 plots)	20 control, 25 treatment (45 plots)

Figures 7, 8, 9 and 10 illustrate the statistical evaluation of the analysis conducted on all control and treatment plots in Azraq. As observed, average water application on control plots was the highest for all crops in the third season. For plots cultivated with grapes and olive, there has been an increasing trend in water application on control plots between the second and third seasons, indicating a change in irrigation practices that led to higher water application in the third season– unlike the situation in Mafraq.

The comparison between the third and fourth seasons for all crops in Azraq was not possible at the time of conducting this study because the data collected in the fourth season does not cover the entire irrigation season. Therefore, plots cultivated with pomegranate and palm dates were excluded from further analysis.

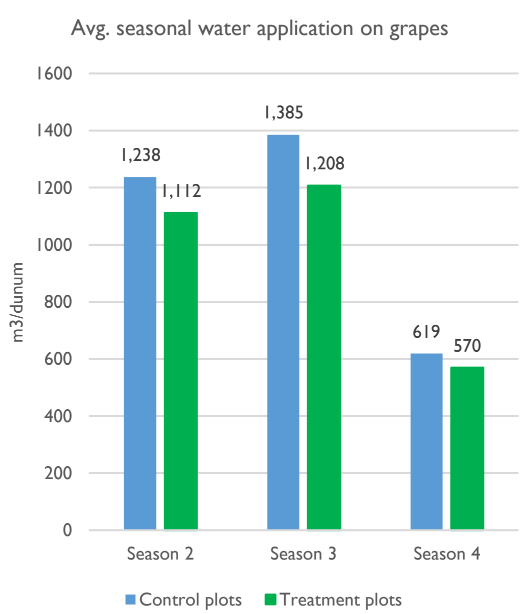

Figure 7: grapes- Azraq.

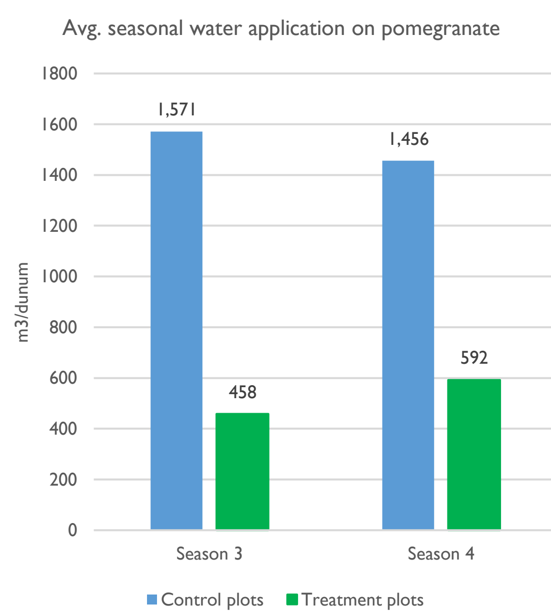

Figure 8: pomegranate– Azraq.

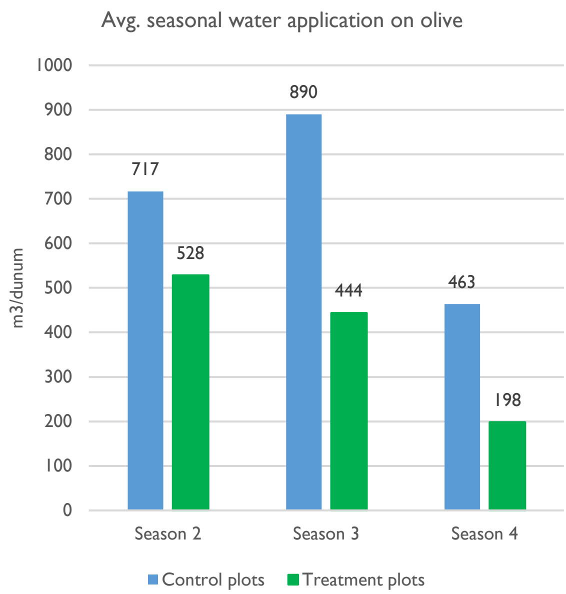

Figure 9: olive- Azraq.

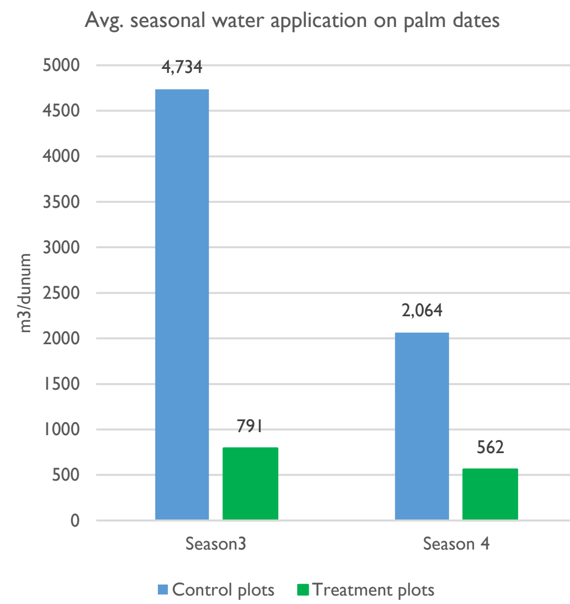

Figure 10: palm dates– Azraq.

3. Hypothesis t-TEST

A t-Test is a type of inferential statistics used to determine a significant difference between the means of two groups. It is used as a hypothesis testing tool that allows testing of an assumption applicable to a population.

In this study, the null hypothesis (H0) is the water savings mean at the population is less or equal to zero, while the alternate hypothesis (H1) is: the water savings mean at the population is significantly higher than zero.

The t-Test was performed on seasonal water savings for each monitored plot with full-time series records for seasons 2 and 3, regardless of the crop type or location. The t-Test aims to determine whether the water savings mean is significantly greater than zero in seasons 2 and 3. The results for the two seasons are presented in (Table 3).

TABLE 3: T-TEST: ONE SAMPLE ASSUMING UNEQUAL VARIANCES

	Water savings season 2	Water savings season 3
MEAN	381.1109686	229.2431011
VARIANCE	592916.5965	553671.1425
OBSERVATIONS	32	34
HYPOTHESIZED MEAN	0	0
DF	31	33
T STAT	2.79981692	1.796427891
P(T<=T) ONE-TAIL	0.00436104	0.040793129

T CRITICAL ONE-TAIL	1.695518783	1.692360309
P(T<=T) TWO-TAIL	0.008722079	0.081586259
T CRITICAL TWO-TAIL	2.039513446	2.034515297

The hypothesis test and decision are summarized in Table 4.

TABLE 4: DECISION MADE.

	Season 2	Season 3
HYPOTHESIS	H0: Savings ≤ 0	H0: Savings ≤ 0
	H1: Savings ≥ 0	H1: Savings ≥ 0
REJECTION REGION	Reject H0 if t > 1.696	Reject H0 if t > 1.692
TEST STATISTICS	2.799	1.796
P-VALUE	0.0043	0.0407
DECISION/CONCLUSION	Because t = 2.799 > 1.696	Because t = 1.796 > 1.692
	Reject H0	Reject H0

Based on the test results, H0 is rejected, and H1 is accepted, meaning that savings are significantly greater than zero in the sample chosen for this analysis. Furthermore, it is evident that the mean water savings in the third season are less than the mean water savings in the second seasons. This difference is explained in the following section.

4. Regression Model

Using Excel, multi-variated regression analysis was conducted to identify the factors that significantly led to less water application on control plots in the third season relative to the second season. The variables initially found to influence the reduction in water savings are as follows:

- Water savings in the second season, X_1;
- Crop type, X_2;
- Total annual rainfall in each of the two governorates (Mafraq and Azraq), X_3.

The difference in water application on control plots in the third season relative to the second season, Y ,was expressed as a function of the above-mentioned factors and as follows:

$$Y = f(X_1, X_2, X_3) \quad \text{................................} (1)$$

The analysis was conducted for a sample of 31 plots where full water application records over the second and third seasons are available, and the results of the model are illustrated in (Table 4).

TABLE 4: REGRESSION MODEL ASSESSMENT.

MODEL AND VARIABLES SIGNIFICANCE				Decision on model
R SQUARE	0.51			51% of the reduction in water application on control plots is explained by the selected variables (precisely water savings in the previous season)
SIGNIFICANCE F	0.000198			Significance F is less than 0.005 – the model is statistically significant
VARIABLES	**Coefficients**	**t Stat**	**P-value**	**Decision on variables**
INTERCEPT	287.21	0.38	0.70	Intercept is 287.21
WATER SAVINGS IN S2	-0.46	-4.88	4.18033E-05	The most significant variable affecting the reduction in water application on control plots in the third season
CROP TYPE	17.30	0.30	0.76	Non-significant variable
RAINFALL IN S3	-0.97	-0.23	0.82	Non-significant variable

Based on the above results, the model can be expressed as follows:

$$y = 287.21 - 0.46\, x_1 \text{ .... (2)}$$

where y=volume of water per unit of land applied to the control plot of a farm (untreated with innovative irrigation technology) in season 3=; and x_1= water savings in season 2.

The model indicates that for each 1 m^3 of water saved in the second season, water application on control plots would decrease by 0.46 m^3 in the third season. The model can be used to estimates of unobserved water savings– water savings that are not tracked using meters or water savings achieved due to the change in farmers' behavior on control plots. In addition, it serves as a forecasting tool to estimate the water saved that can be achieved on farms not monitored by WIT. Table 5 provides descriptive statistics of the modelling results that inform the estimation of unobserved water savings.

TABLE 5: DESCRIPTIVE STATISTICS OF UNOBSERVED WATER SAVINGS (FROM BEHAVIOURAL CHANGE ON CONTROL PLOTS).

MEAN	108
MEDIAN	222
STANDARD DEVIATION	359
RANGE	1865
MINIMUM	-1359
MAXIMUM	507

From the table above, we conclude that water savings from the change in irrigation behavior on control plots range between (-1,359 and 507) m^3/dunum or practically between (0 and 507) m^3/dunum. Average water savings stand at 108 m^3/dunum, meaning that for farmers who adopt water saving technologies, water savings recorded by meters in the third season are less than the actual savings achieved due to the adoption of water saving technologies by an average of 108 m^3/dunum. These results are specifically implementable in the third season after adopting water saving technologies. Calculating water savings of the following seasons shall require conducting the same analysis using season 3 and 4 field data.

CONCLUSION

The main output from this learning activity is to test the hypothesis that information on water volumes applied are significant explanatory variables for the change in farmer irrigation behavior. The analysis supports this hypothesis. The analysis results indicate a change in irrigation behavior among 51% of the studied plots. This change has led to fewer water savings recorded by meters; however, implicitly, savings in this group of plots was higher than what is recorded by meters, mainly due to the reduction in water application on control plots. This has implications for investment in water savings technology. To date, water meters are only installed at wells and are perceived primarily as a tool for water billing, and it is water tariffs are used as an instrument to influence farmer irrigation behavior.

However, the hypothesis of this learning agenda question indicates that water metering within a farm, e.g., on individual zones, and more importantly, information that farmers efficiently synthesize, is also a water savings technology in its own right alongside drip irrigation technologies. Water accounting, therefore, is considered a suitable tool to influence farmers' water use behavior and achieve a sustainable positive change in their attitude towards water.

The efforts paid by WIT, suppliers, and other partners in explaining the benefits of water saving technologies and the associated practices. Providing farmers with crop water requirements also improved their knowledge and enhance their willingness to reduce the amounts to be close to the actual requirements. The last intervention was the result base package that encouraged suppliers to get involved in the irrigation management and guide farmers to best practices. This obviously helped farmers in reducing water consumption on all plots (T&C).

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