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Views, practices and knowledge of farmers regarding smart irrigation apps: A national cross-sectional study in Lebanon

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ABSTRACT

Smart irrigation techniques have the potential for improving water application efficiencies at the farm level, thereby helping to reduce the environmental impact of agriculture and providing an economic advantage to farmers. Here we gauge the willingness of farmers to use smart irrigation techniques in water management by conducting a cross-sectional national survey of 678 farmers in Lebanon. A primary objective was to find out whether farmers are willing to adopt the use of smart irrigation mobile applications in their cultural practices. Other survey questions were designed to find out the drivers of the willingness or lack thereof. Descriptive statistics along with simple/multiple logistic regression analyses were performed to explore the associations of sociodemographic variables, cultivated land, water and fuel cost, irrigation system type, groundwater depth, water source, and other irrigation management characteristics with the likelihood of using a free smart irrigation application in the study population. Results revealed that 90% of farmers agree that better irrigation management can improve the economic productivity of their farms, and a similar percentage agreed that they are willing to use free smart mobile applications to assist them in managing (scheduling) irrigation for their crops. Results also indicated that among all sociodemographic characteristics considered in this study, age, nationality, and region were significantly associated with the use of a paid smart irrigation app. Willingness to pay was 57%, with younger farmers and those using energy or electricity, and those paying more for energy and water, more willing to pay. Farmers planting citrus and banana trees were more likely to use smart irrigation apps than those planting other crops such as potatoes and vegetables. The findings help identify the factors influencing the adoption of smart irrigation applications in agriculture, which will provide insights into the interlinkages between irrigation management and infrastructure and sociodemographic variables.

1. Introduction

A sizeable proportion (85%) of the total water resources available around the world are exclusively used for irrigation purposes (Vaishali et al., 2017). The smart management of these freshwater resources for precision irrigation in agriculture is essential for enhancing crop yield and water productivity, improving irrigation scheduling, decreasing farming costs while sustaining the environment (Dobbs et al., 2014; Paredes et al., 2018; Pereira et al., 2015; Rosa et al., 2012; Seidel et al., 2016; Zotarelli et al., 2011; Jaafar et al., 2017). Irrigation practices will have to evolve and meet the increasing global demand for water and food. Smart irrigation techniques have a potential for improving water application efficiencies at the farm level, which would help reduce the environmental impact of agriculture and, at the same time, provide an economic advantage to farmers (Levidow et al., 2014). The adoption of technologies in agriculture, especially irrigation technologies, can result in improvements in crop yields. But many of these technologies require the availability of extension services, which still fall short of providing the required expertize to farmers for proper adaptation and implementation in many developing countries. Farmers do not have enough incentives to adopt such high-cost investments on their own (McLaren et al., 2009). While the costs of some irrigation scheduling systems are decreasing (such as sensors, web platforms, apps, and online irrigation services), these solutions may still be cost-unaffordable if it does not

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significantly increase farmers' income, especially with moderate- to low-profit crops (Levidow et al., 2014). With the advancement of climate-based methods in estimating agricultural water requirements and use (Ouédraogo et al., 2018), irrigation information can be provided for farmers via smartphone applications that can relay such information. Information about precise irrigation applications and schedules can enhance the resilience of the irrigated agriculture sector under a changing climate (Padgham, 2009). While a significant percentage of agricultural stakeholders in some areas of the world have been reported to be willing to pay for such applications (Bartlett et al., 2015), farmers' preferences for using smart irrigation applications are still not well understood. Incentives for farmers' willingness to better manage their irrigations are not always apparent or existing. Understanding the drivers of improved water management among farmers can lead to improved environmental benefits while at the same time, increasing agricultural productivity and improving farmers' livelihood. The adoption of climate-smart agricultural technologies among farmers is marked by commonalities as well as differences, with local climate and socio-economic characteristics being the significant factors in affecting the adoption (Khatri-Chhetri et al., 2017). The objective of this study is to identify how sociodemographic and economic variables such as age, education, and cost of irrigation associate with irrigation decision drivers and farmers perception of water management and a willingness to use smart irrigation apps. We assess current irrigation management practices that are implemented by farmers in Lebanon, and gauge the possibility for farmers adopting an emerging technology in irrigation (a smart irrigation mobile app). The outcome of this study could potentially help to propose new smart irrigation management approaches that would not only help farmers to better manage their irrigated land but also help them reduce their energy, fertilizers, and water costs. This study will help answer the following questions: 1) are the farmers willing to manage their irrigation water? 2) Are they willing to use some technology to do so? How is their perception of technology use, namely smart mobile applications, affected by their crops, irrigation systems, water sources, and irrigation operation costs? 3) Do farmers relate better irrigation management to improved crop yields and reduced energy and fertilizers input?

2. Methods

2.1. Data collection procedure

A descriptive cross-sectional survey was conducted among farmers in Lebanon from September 2019 to February 2020. These farmers either operate their farms or work on rented land or land farmed on shares. Farmers from the main irrigated agricultural areas of Lebanon (South Lebanon, Akkar, Nabatiye, Mount Lebanon, Baalbeck-Hermel, and Bekaa governorates) were approached. Farmers who own land over one hectare were the primary sampling unit and selected from an existing list compiled by the Ministry of Agriculture (MoA) using a stratified random sampling approach. The governorates mentioned above formed the various strata. Farmers within each stratum (governorate) were chosen randomly from the list of all farmers in that stratum based on probability proportional to size sampling. Sample size calculations showed that a sample of 577 farmers would be necessary to estimate a prevalence of 50% with a 95% confidence interval (CI) and at 5% significance level. A final sample of 678 farmers was chosen from the MoA list to account for a refusal rate of 15%.

To be eligible to participate in the study, the farmer ought to (1) be aged 18 and above, (2) own land more than 1 ha (because of the difficulty in identifying parcels less than 1 ha on freely available satellite imagery, farmers who reported to hold less than this area were excluded from the study), (3) have no mental disability that would prevent reading and understanding and (4) be acquainted in either English or Arabic languages. The study was ethically approved by the Institutional Review Board (IRB) at the American University of Beirut prior to the sampling. Interested farmers who met the eligibility criteria were provided with a consent form that explained the objective of the study, procedures to be undertaken, potential risks and benefits of participation, and all related information. Farmers were urged to ask any questions regarding the research study or request further clarification before they agree to take part in the survey. Farmers who agreed to participate had to sign the consent form before the initiation of the study. A copy of the consent form was kept with farmers in case they had any complaints or concerns regarding the study. Farmers were excluded if they refused to give consent for the study. Further, if a farmer in a chosen farm was unable or refused to take part in the study, the farmer in the closest farm was approached. When more than one eligible farmer was found on the farm, one was randomly chosen by the interviewer.

2.2. Survey instrument

The data collection approach was conducted on the selected farm in a private setting. A multicomponent questionnaire was filled out by eligible farmers during a face-to-face interview session which lasted between 10 and 30 min. The interview sessions were performed by field workers who underwent intensive training on the application of the interview protocol and administration of the questionnaire before the initiation of the survey. The questionnaire was initially developed in English, subsequently translated to the Arabic language (since most of the farmers talked Arabic) and then back-translated to English. The two translations were carried out to verify the parallel-form reliability of the questionnaire. Any disagreement that occurred in the back-translated version was resolved to provide a precise reading.

The questionnaire consisted of four sections. Section 1 included questions linked to sociodemographic and education, such as age, sex, nationality, village, governorate, and the highest level of education attained (Primary school, Intermediate school, High school, University degree or Technical). Section 2 addressed questions related to farmer's cultivated land or agricultural area, such as place, village, number of irrigated plots, the area of each plot, irrigation decision drivers (such as soil moisture-based or weather station -based irrigation scheduling, or cropstress based irrigation scheduling), and the irrigation interval. Another key question related to the farmer's ability to locate their land (s) on Google Maps and or satellite imagery using their phone or internet. Other issues covered type of crop, length of the growing season (duration in days), the distance between trees or plants (m), the quantity of production (ton/season), or (ton/ha) and hours of irrigation (hr). Specific questions were related to water for irrigation (such as hours of flooding (hr), quantity (m^3), cost/Season ($)), and fuel for irrigation such as quantity (liter or kilowatt) and cost/season ($). Section 3 included questions assessing the farmer's current irrigation system, such as water source and capacity (river or spring, irrigation channel, well or purchase water), type of the well (drill or reservoir), characteristics of the well and the pump (depth of well (m), pump size, whether it operates using fuel or electricity, water pressure (PSI) or (bar), flow (m^3/hr), pump power (H.P.)). Other questions covered the irrigation network such as the main pipeline size (mm), lateral size (mm), lateral length (m), number of laterals, laterals' spacing (m), irrigation systems used (solid-set sprinkler, micro-sprinkler, periodic move, drip, bubbler, or surface irrigation) and whether they have used irrigation metering, and control devices. The last section of the questionnaire addressed the farmer's attitude towards improving irrigation management and adopting smart irrigation. A total of seven questions were selected, four of which tackling the view on whether irrigation management helps to increase the yield, to reduce the cost of irrigation, to reduce the cost of fuel, and to reduce the cost of electricity. The other three questions related to the farmer's willingness to manage irrigation for their crops better and to use a free (or non-free) smart mobile application to assist them in managing (scheduling) irrigation system for their crops. Here the questionnaire employed a 5-point Likert rating scale in which 1 denoted strongly disagree and 5 denoted strongly agree. A final question

Table 1
Sociodemographic characteristics of study sample (n = 679).

	Total sample
A. Sociodemographic characteristics	
Age	52.05 ± 12.74
18–40 years	117(17.2)
40–65 years	454(66.9)
≥ 65 years	108(15.9)
Gender	
Male	673(99.1)
Female	6(0.9)
Nationality	
Lebanese	592(87.2)
Syrian	55(8.1)
Palestinian	26(3.8)
Egyptian	6(0.9)
Education	
Elementary or less	199(29.3)
Intermediate	250(36.8)
Secondary	118(17.4)
University degree	112(16.5)
Region	
Bekaa	190(28.3)
North	81(12.1)
South	400(59.6)
B. Cultivated land	
Number of irrigated lands	1.9 ± 0.10
Total area of land (ha)	142.2 ± 13.6
Irrigation interval (days)	9.0 ± 0.58
Ability to locate your land (s)	
No	328(48.3)
Yes	351(51.7)
C. Water source, method of irrigation and irrigation water use	
Water source	
River or spring	31(4.6)
Canal	82(12.1)
Spring-River-Canal	11(1.6)
Spring-River-Well	35(5.2)
Well	466(68.6)
Well-Canal	44(6.5)
Buy Water	10(1.5)
Well use	
Yes	516(95.4)
No	25(4.6)
Well depth (m)	161.7 ± 5.3
Irrigation system	
Drip only	235(34.6)
Sprinkler and drip	86(12.7)
Traveling sprinkler	153(22.5)
Surface and pressurized	104(15.3)
Surface only	101(14.9)
Flow meter	
No	636(93.7)
Yes	43(6.3)
Energy type	
Fuel	364(66.5)
Electricity	69(12.6)
Both	107(19.6)
Other	7(1.3)
Water cost ($/ha/season)	272.5 ± 17.12
Fuel cost ($/ha/season)	547.8 ± 21.6
Total cost ($/ha/season)	807.2 ± 23.5
Major crop	
Potato	130(19.1)
Vegetables	80(11.8)
Citrus/Banana/Other tropical	396(58.3)
Other fruit trees	73(10.8)

Continuous variables are presented as means with their standard deviations, whereas categorical variables are reported as frequencies and proportions (i.e. n (%))

in the survey related to the type of information the famer's view to better manage their irrigated land, such as innovative irrigation practices/equipment, irrigation scheduling guidelines/standards, crop management guidelines, crop water requirements or soil management guidelines. A pilot study was conducted on a convenient sample of 10 farmers to check for consistency, clarity and culture sensitivity. The results of the pilot testing phase of the questionnaire were not included in this study. A copy of the questionnaire used in data collection is available from the authors upon request.

2.3. Statistical analysis

Data entry and statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software version 24 for Windows. Frequencies and proportions were used to describe categorical variables and means ± standard deviations (SD) for continuous ones. We use the independent t and Chi-square tests to calculate significant differences among continuous and categorical variables, respectively. Examples of differences are sociodemographic characteristics, farmer's ability to locate their land (s) on Google Maps using their phone or internet, and farmer's likelihood to use a free and/or non-free smart mobile application to assist them in managing (scheduling) irrigation system for their crops. Simple and multiple logistic regression analyses were applied to explore which factors are associated with the odds of using a free or non-free smart mobile application. Sociodemographic variables (age, gender, highest educational credential, the region of residence, number of irrigated plots), and irrigation-related variables (water source, hours/quantity/cost/ of irrigation, and quantity/cost/ of fuel for irrigation) were included in the regression model as independent variables. The likelihood to use a free and/or non-free smart mobile application to assist them in managing (scheduling) irrigation system for their crops, which was coded as 0 = Unlikely (combined strongly disagree, disagree and neither agree or disagree) and 1 = Likely (combined agree and strongly agree) was included as the dependent variable. All sociodemographic and irrigation-related characteristics which were statistically significant in the simple logistic model were incorporated into the multiple one as independent variables. The multiple logistic regression model was applied to investigate the associations of the sociodemographic variables, cultivated land, and irrigation management characteristics with the likelihood of using a free smart irrigation application in the study population. The multiple regression analysis was used to estimate the association between a given independent variable and the likelihood of using a free smart irrigation application while controlling for potentially confounding variables that have been used in the model. Findings from the logistic regression were expressed in terms of odds ratios (OR) and their respective 95% confidence intervals. All analyses used in the study were two-tailed, and a p-value < 0.05 was considered statistically significant. Farmers imposed no direct input into the design, conduct, or reporting of the survey.

3. Results

3.1. Description characteristics and statistics

3.1.1. Characteristics of the overall study population

Table 1A displays the sociodemographic characteristics of the farmers who participated in the study**.** The farmers were of different age groups, with the majority of them aged between 40 and 65 years (66.9%). Most of the farmers in the study sample were Lebanese (87.2%) and consisted of males (99.1%) and females (0.9%). Two-thirds of the study sample had an intermediate school level or less, 17.4% completed a secondary school level, while 16.5% attained a university degree. Over 50% of the farmers were from agricultural areas in the southern part of the country (59.6%), with 28.3% from the inland areas (Bekaa, Baalbeck–Hermel) and 12.1% from the Northern region (Akkar, North Lebanon).

3.1.2. Information related to cultivated land or agricultural area

Overall, participants owned on average of two irrigated plots with a mean total area of owned land of 14.2 ha, and average parcel size of 8 ha. The average irrigation interval that the farmers adopt in the country

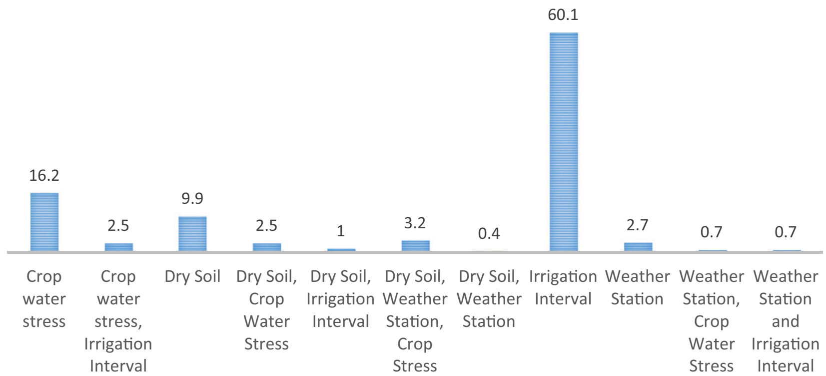

Fig. 1. Survey results regarding farmers' decision on their irrigation scheduling triggers (% of farmers). Most farmers indicated that they irrigate based on a fixed irrigation interval.

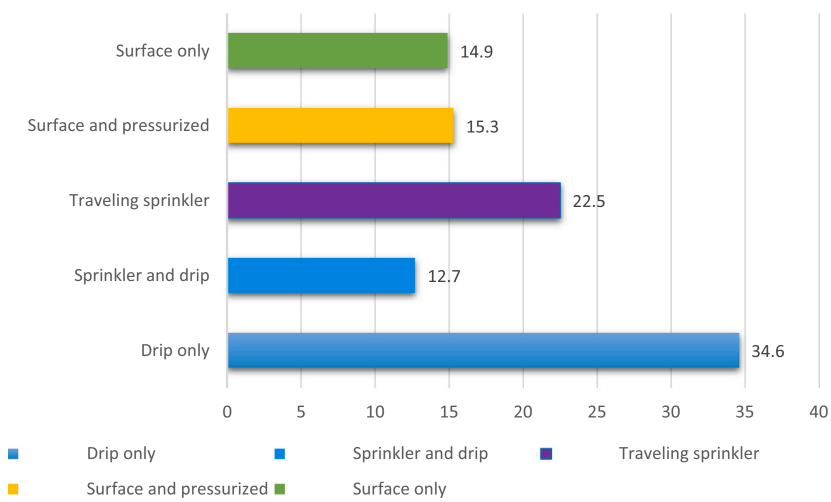

Fig. 2. Irrigation systems used by the farmers in this study (%). A large percentage of farmers in Lebanon rely on drip and sprinkle irrigation.

was nine days, with variability between 3 days and 1 month, depending on the crop and the irrigation system used (trees, row or field crops, and surface vs. drip or sprinkle) (Table 1B). Major plants of irrigated lands among Lebanese farmers included citrus/banana/other tropical crops (avocados, custard apple, mango trees) (58.3%), potato (19%), vegetables (11.8%), and other fruit trees (10.8%). Half of the participants (51.7%) said they were able to locate their land (s) on Google Maps and or satellite imagery using their phones or personal computers.

3.1.3. *Evaluation of farmer's current irrigation system*

Table 1C displays the results on the farmer's current water source, method of irrigation, and irrigation water use. Results revealed that farmers used various water sources for irrigation, with a prevalence of reliance on groundwater. Most participants used groundwater for irrigation (68.6%) followed by canal water (12.1%), a combination of groundwater and canal water (6.5%), a combination of spring and river and groundwater (5.2%), and river or spring water (4.6%). About 1.5% reported purchasing water for irrigation. Concerning the primary water source, the vast majority of participants (95.4%) reported using deep wells for irrigation of their crops with an average well depth of 162 (SD 5.3) meters, with the rest using dug cisterns.

Irrigation scheduling is one of the critical factors that may help farmers to optimize their water use. The majority of the farmers reported irrigating at a fixed irrigation interval (60.7%), followed by some indication of crop water stress (16.2%), and dry soil (9.9%) (Fig. 1). Regarding the irrigation system, farmers reported various irrigation methods including drip irrigation only (34.6%), sprinkler and drip (12.7%), sprinkle only (22.5%) surface and pressurized irrigation (15.3%), and surface irrigation only (14.9%) (Table 1 and Fig. 2). Few participants (6.3%) reported using an irrigation metering or timing devices. Almost two-thirds of study participants said fuel as an energy source for irrigation of cultivated land, 12.6% reported using electricity, and 19.6% reported using both energy sources. On average, the annual water and energy costs per hectare were estimated at 272 USD and 548 USD, respectively.

3.1.4. *Views related to irrigation management and smart irrigation*

Overall, farmers in the study sample showed positive general views corresponding to irrigation management with 89.4% and 88.2% of farmers strongly agreeing or agreeing that irrigation management helps to increase the yield and reduce the cost of irrigation, respectively (Table 2 and Fig. 3). Only 10% disagreed or strongly disagreed that irrigation management helps reduce the cost of fuel (4.3% were neutral, and 6.5% strongly disagreed or disagreed) or lower price of electricity (4.7% were neutral, and 5.6% strongly disagreed or disagreed). More than 90.0% strongly agreed or agreed that they are willing better to manage irrigation for their crops (Table 2). As for the farmers' views related to the use of the smart mobile application, the majority of farmers (89.3%) agreed or strongly agreed that they are willing to use a free smart mobile app to assist them in managing (scheduling) irrigation system for their crops. When asked if they are ready to use a paid smart mobile application to assist them in managing (scheduling) irrigation, 60.6% of surveyed farmers agreed or strongly agreed.

Table 2
General views towards irrigation management among study sample (n = 679).

	Strongly agree n (%)	Agree	Neutral	Disagree	Strongly disagree
A. Irrigation management helps to:					
1. Increase the yield	544 (82.4)	46 (7.0)	23(3.5)	22(3.3)	25(3.8)
2. Reduce the cost of irrigation	529 (80.0)	54 (8.2)	26(3.9)	24(3.6)	28(4.2)
3. Reduce the cost of fuel	539 (82.7)	43 (6.6)	28(4.3)	20(3.1)	22(3.4)
4. Reducing the cost of electricity	525 (82.7)	44 (6.9)	30(4.7)	18(2.8)	18(2.8)
B. You are willing to:					
5. Manage irrigation for your crops	551 (82.5)	51 (7.6)	27(4.0)	18(2.7)	21(3.1)
6. Use a free smart mobile application to assist them in managing (scheduling) irrigation system for their crops	517 (78.1)	74 (11.2)	29(4.4)	13(2.0)	29(4.4)
7. Use a non-free smart mobile application to assist them in managing (scheduling) irrigation system for their crops	98(15.1)	295 (45.5)	86 (13.3)	39(6.0)	131 (20.2)

3.2. Interactions between the studied variables

3.2.1. Associations between sociodemographic characteristics of the study sample, the ability to locate land, and general perspectives about irrigation management Views

Education and age were significantly associated with farmer's ability to locate their land (s) on Google Maps and or satellite imagery using their phone or internet (Fig. 4). Almost two-thirds of the farmers who reported their ability to locate land were aged 40–65 years, and 50% had intermediate education or below ($p < 0.001$, Fig. 4). A higher proportion of farmers who reported that irrigation management may help increase yield reside in the South region of the country (59.6%) as compared to those in Bekaa or North (30.3% and 10.1%, $p < 0.05$, Fig. 5). From those who agreed that irrigation management helps to increase yield, 63.9% had (<=intermediate education level), 18.1% had secondary and 18% had University degrees, Fig. 5)). Among participants who reported that irrigation management may reduce water use, most of the farmers were residing in South region (60.7%), completed intermediate education or below (63.0%) and aged 40–65 years (62.8%) (Fig. 6). Additionally, a significantly ($p < 0.05$) higher proportion of farmers who reported that irrigation management may help reduce fuel and electricity cost had intermediate education or less (63.4% and 62.9%, Fig. 7 and Fig. 8). Also, most surveyed farmers who agreed or strongly agreed to manage irrigation crops, were found to be residing in South region (60.9%) and had intermediate education or less (64.1%, Fig. 9).

3.2.2. Associations of sociodemographic characteristics of study sample, cultivated land and irrigation properties with the use of smart irrigation mobile application (free and paid)

Table 3 displays the associations between characteristics of study sample and the use of smart irrigation mobile application (free and paid) to assist farmers in managing irrigation system for crops. Results indicated that there was a statistically significant association between age, region, and the use of smart irrigation mobile applications (free and paid). Most study participants who reported the willingness to use free and paid smart irrigation mobile application to manage crops reside in South Lebanon (61.1% and 71.8%, respectively), as compared to Bekaa (27.1% for free and 19.5% paid) and North Lebanon (11.8% for free and 8.7% for paid). Most of them reported willingness to pay for smart apps plant tropical crops (e.g., citrus, banana) (69.2%), as compared to other groups (14.8% for those with potato crops, 9.2% for those with vegetable crops and 6.9% for those with other fruit trees, $p < 0.001$). As for the cultivated land, results revealed that the association between the number of irrigated plots and the use of paid smart irrigation mobile application was statistically significant (2.3 vs 1.7, $p = 0.007$), with farmers having a higher number of parcels being more willing to pay.

With regards to the water source, method of irrigation, and irrigation water use, the analysis indicated that the association between water source and views about irrigation management and the use of smart irrigation mobile application was statistically significant (free and paid). For instance, most participants who agreed or strongly agreed to use a free or paid smart irrigation mobile application ($p < 0.05$) reported using groundwater or diverting their water from irrigation canals. Additionally, findings indicated a statistically significant association between well depth and irrigation systems and the use of free smart irrigation mobile app. More specifically, a significantly greater well depth was observed among farmers who agreed or strongly agreed to use a free smart irrigation mobile application compared to their counterparts (131.0 ± 12.6 vs. 164.4 ± 5.7, $p = 0.002$). Furthermore, those

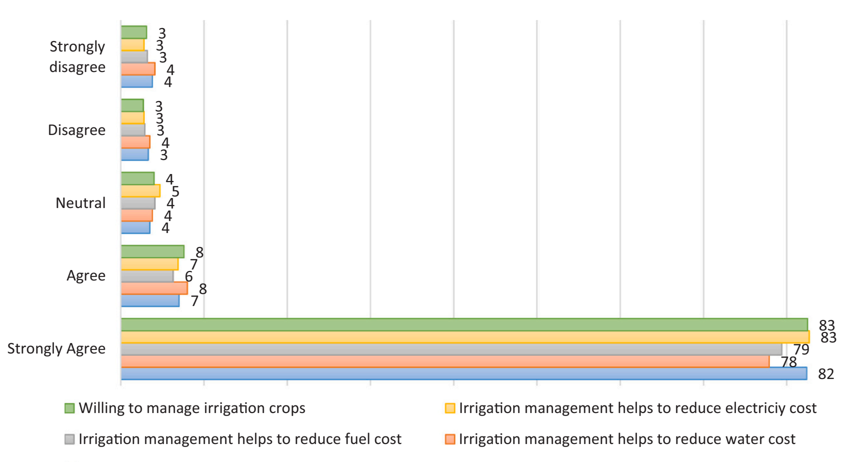

Fig. 3. Famers general views towards irrigation management (%). A vast majority of farmers agree that managing irrigation would help improve yields while reducing energy and water costs.

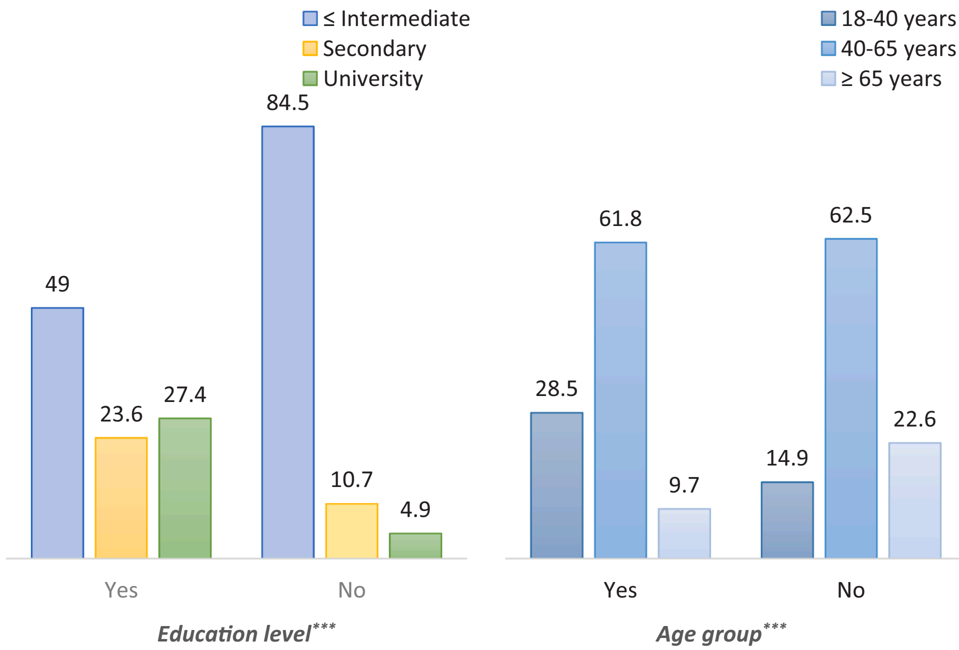

Fig. 4. Farmers views (Yes, No) regarding their ability to locate land (s) on Google Maps or satellite imagery using their phone or internet (%) by their age and education level. Most farmers who believe they cannot locate their lands on satellite imagery have an intermediate education or less. (*** indicates significance at $p < 0.001$).

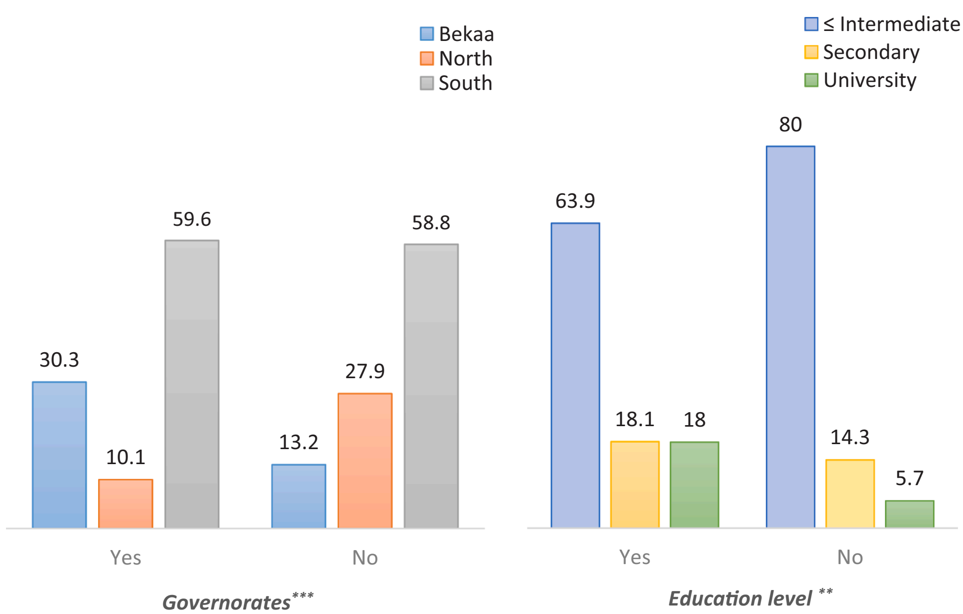

Fig. 5. Farmers views whether irrigation management helps to increase yield by governorate and education level (%) (** indicates significance at $p < 0.05$, and *** indicates significance at $p < 0.001$).

who reported using drip (34.3%) and sprinkler (23.0%) only agreed or strongly agreed to use a free smart irrigation mobile application as compared to other groups (15.9% for those with surface and pressurized, 14.6% for those with surface only and 13.2% for those with sprinkler and drip, $p = 0.023$). Analysis also showed that the association between use of flow meter and energy type and the use of paid smart irrigation mobile application was statistically significant ($p = 0.025$ and $p < 0.001$). A statistically significantly ($p < 0.05$) higher total irrigation cost was noticed among those who agreed or strongly agreed to use a paid smart irrigation mobile application compared to their counterparts (849.3 ± 28.3 vs. 745.7 ± 43.3, $p = 0.038$).

As far as irrigation management is concerned, a significantly greater proportion (91–97.7%) of study participants who reported that irrigation management might help increase yield, reduce the cost of irrigation, fuel, and electricity, and those who were willing to manage irrigation practices agreed or strongly agreed to use a free or paid smart irrigation mobile application ($p < 0.001$). More than half of study participants (52.3%) who were not willing to manage irrigation practices of their crops disagreed or strongly disagreed on the use of free smart irrigation mobile applications as compared to those who were prepared to manage irrigation practices in their fields (47.7%).

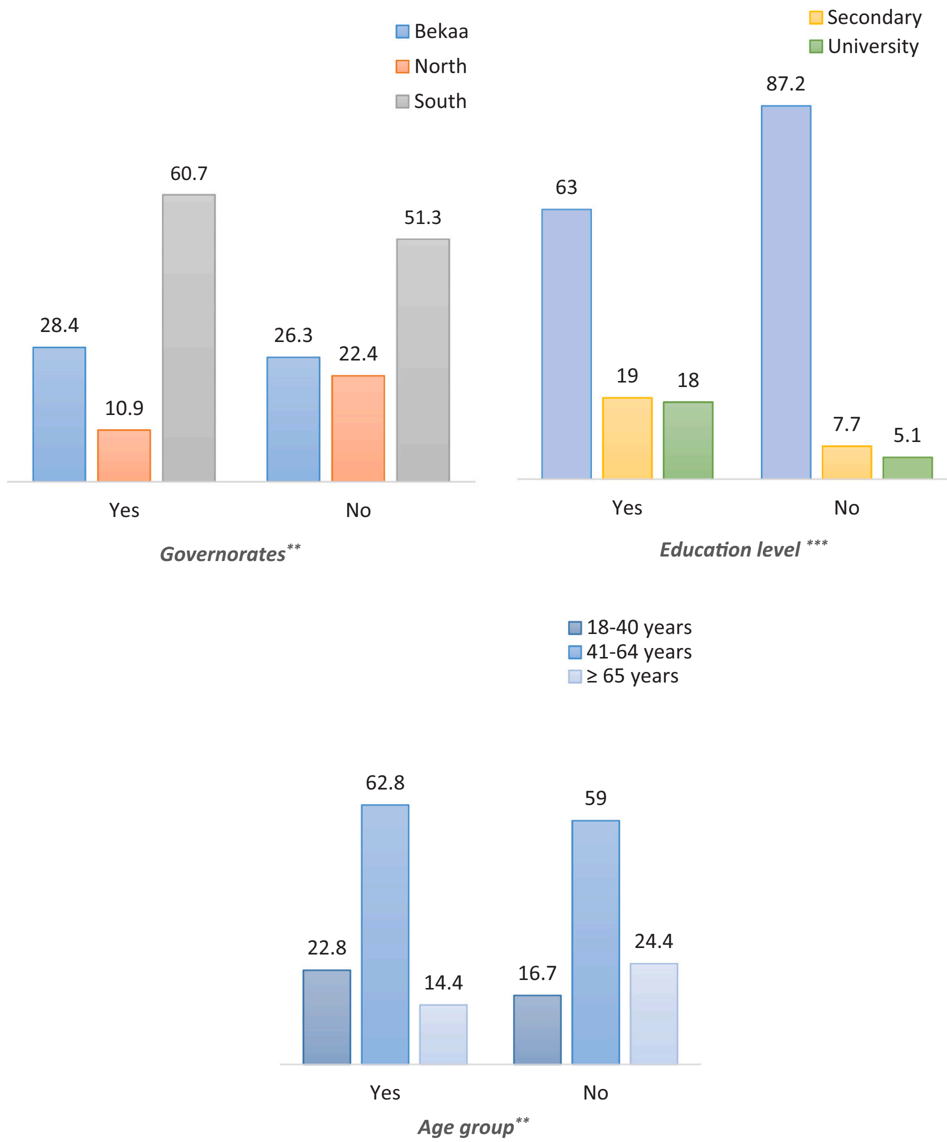

Fig. 6. Farmers views whether irrigation management helps to reduce water use (%) by age group, governorate, and education level (** indicates significance at $p < 0.05$, and *** indicates significance at $p < 0.001$).

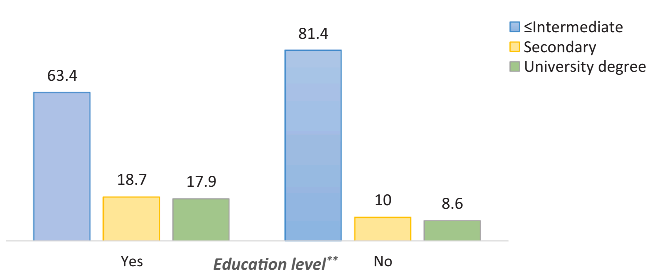

Fig. 7. Farmers views whether irrigation management helps to reduce fuel cost by education level (%) (** indicates significance at $p < 0.05$).

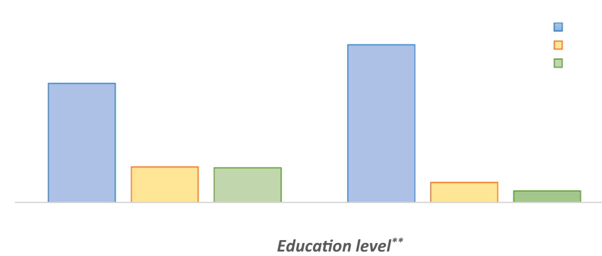

Fig. 8. Farmers views whether irrigation management helps to reduce electricity cost by education level (%) (** indicates significance at $p < 0.05$).

3.2.3. Farmers' likelihood for using free smart irrigation mobile application

Simple logistic regression analysis revealed that among all socio-demographic characteristics considered in the study sample, age and region were significantly associated with the use of free smart irrigation mobile application in the study sample (Table 4). Older study participants (aged 65 years or above) were significantly less likely to agree or strongly agree to use a free smart irrigation mobile application compared to their counterparts (OR = 0.31, 95% CI: 0.12, 0.84, p = 0.012). Also, participants residing in South Lebanon were twice more likely to agree or strongly agree to use a free smart irrigation mobile application compared to those living in Bekaa or North Lebanon (OR = 1.90, 95% CI: 1.10, 3.3, p = 0.021). With regards to irrigation water, the sources of the water, irrigation system, and the price the farmers pay for this water were all significantly correlated with the use of smart irrigation mobile application. More specifically, participants

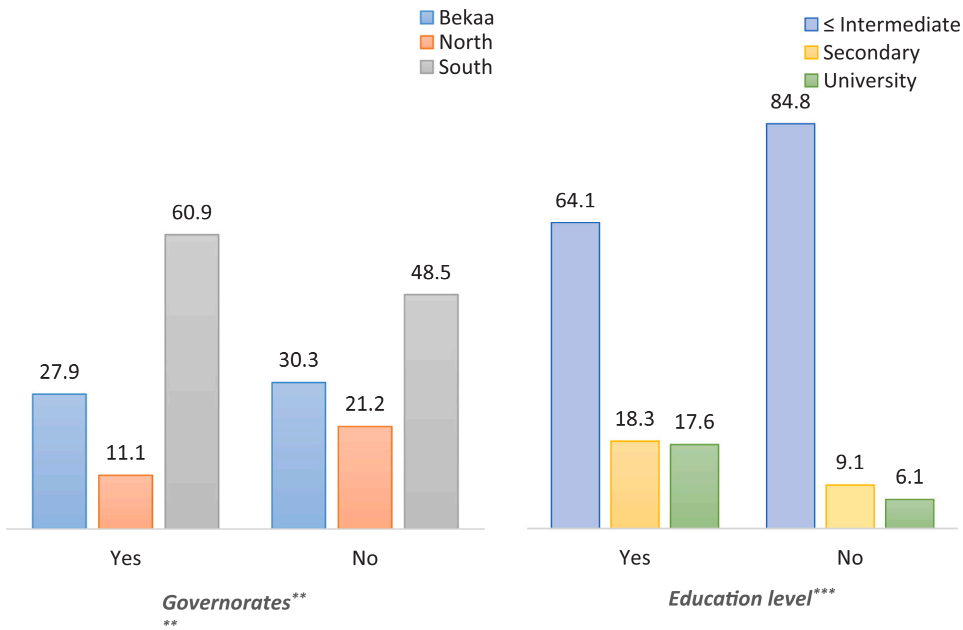

Fig. 9. Farmers willing to manage irrigation crops by governorate and education level (%). Out of the small percentage of farmers who said they are not willing to manage their water, 85% of them have an intermediate education or less. (** ** indicates significance at $p < 0.05$, and *** ** indicates significance at $p < 0.001$).

who reported using the groundwater water for irrigation were four times more likely to agree or strongly agree to use a free smart irrigation mobile application compared to those who use spring or river water for irrigation (OR = 3.8, 95% CI: 1.6, 8.8, $p = 0.002$). Additionally, farmers who reported using the sprinkler only or surface and pressurized systems were three times more likely to agree or strongly agree to use a free smart irrigation mobile application compared to those who use surface irrigation only (OR = 3.2, 95% CI: 1.2, 8.5, $p = 0.017$; OR = 2.8, 95% CI: 1.3, 6.1, $p = 0.008$).

All views about irrigation management were significantly associated with the odds of the use of free smart irrigation mobile application. Participants who reported that irrigation management might help increase yield were significantly five times more likely to say "agree" or "strongly agree" to use a free smart irrigation mobile application (OR = 5.5, 95% CI: 3.1, 10.0, $p < 0.001$). Similarly, participants who agreed or strongly agreed that irrigation management may help reduce water use, fuel and electricity cost were significantly more likely to report "agree" or "strongly agree" to use a free smart irrigation mobile application (OR = 5.1, 95% CI: 2.8, 9.1; OR = 4.9, 95% CI: 2.6, 9.0; OR= 4.4, 95% CI: 2.3, 8.4 respectively, $p < 0.001$). Willingness to manage irrigation of crops among the study sample was significantly associated with higher odds of using a free smart irrigation mobile application and vice versa (OR = 26.9, 95% CI: 14.2, 51.0, $p < 0.001$).

3.2.4. *Multiple logistic regression analyses*

A multiple logistic regression model was used to estimate the correlations of free or paid smart irrigation application use in the study sample (Table 4). Variables were entered into the model in order of their correlation strength with free or paid smart irrigation application use as per the simple analysis. The impact of every variable on the model was examined and consequently was maintained in the model if it contributed significantly to a better fit. The following variables: age, region, water source, and water cost, irrigation system, and irrigation management variables were all included in the final multiple logistic model (Table 4). The analysis revealed that likelihood to use a free smart irrigation application in the study population was significantly associated with the region ($p = 0.025$), those who applied both surface and pressurized irrigation methods to irrigate crops ($p = 0.008$), water cost ($p = 0.007$) and willingness to manage irrigation ($p < 0.001$). Participants residing in South Lebanon were three times more likely to agree or strongly agree to use a free smart irrigation mobile application compared to those living in Bekaa or North Lebanon (OR = 3.0, 95% CI: 1.1, 7.9, $p = 0.025$). Also, participants who reported using a combination of surface and pressurized irrigation systems were seven times more likely to agree or strongly agree to use a free smart irrigation mobile application for irrigation (OR = 7.0, 95% CI: 1.7,29.6, $p = 0.008$). After controlling for covariates, willingness to manage irrigation crops among the study sample remained significantly associated with higher odds of using a free smart irrigation mobile application (OR = 33.8, 95% CI: 10.2111.4 $p < 0.001$).

3.2.5. *Farmers' likelihood of using paid smart irrigation mobile application*

Simple logistic regression analysis revealed that among all socio-demographic characteristics considered in the survey, age, nationality, and region were significantly associated with the use of paid smart irrigation mobile application in the study sample (Table 5). For instance, participants belonging to both middle-age group (40–65 years) and older age group (65 years and above) were significantly less likely to agree or strongly agree to use a paid smart irrigation mobile application compared to younger age group respectively (OR = 0.30, 95% CI: 0.16, 0.56, $p < 0.001$; OR = 0.30, 95% CI: 0.16, 0.54, $p < 0.001$). Younger age was correlated with the use of a free and paid mobile app. 86% of participants younger than 40 years are willing to pay, compared to 56% of the other group ages.

Additionally, participants residing in South Lebanon were 3.7 times more likely to agree or strongly agree to use a paid smart irrigation mobile application compared to those living in Bekaa or North Lebanon (OR = 3.7, 95% CI: 2.54, 5.35, $p < 0.001$). Also, Lebanese participants were less likely to agree or strongly agree on using a paid smart irrigation application to manage crops as compared to non-Lebanese (OR = 0.54, 95% CI: 2.54, 5.35, $p < 0.001$).

With regards to cultivated land, the number of irrigated farms and major crops was both significantly associated with the use of paid smart irrigation mobile application. More specifically, participants with tropical crops (e.g., citrus fruits and banana) or other fruit trees were twice more likely to strongly agree to use a paid smart irrigation mobile application for irrigation as compared to those with potato or vegetables or other fruit crops (OR = 2.3, 95% CI: 1.5, 3.5, $p < 0.001$). With

Table 3
Associations of sociodemographic characteristics of study sample, cultivated land and irrigation properties with the use of smart irrigation mobile application (free and paid).

	Free application		Significance	Paid Application		Significance
	No	*Yes*		*No*	*Yes*	
A. Sociodemographic characteristics						
Age	56.6 ± 13.0	51.5 ± 12.5	**p = 0.001**	54.8 ± 11.6	50.4 ± 12.9	**p < 0.001**
18–40 years	6(8.5)	106(17.9)	**χ^2 = 5.6,p = 0.060**	21(8.2)	86(21.9)	**χ^2 = 21.1,p < 0.001**
40–65 years	49(69.0)	396(67.0)		190(74.2)	251(63.9)	
≥65 years	16(22.5)	89(15.1)		45(17.6)	56(14.2)	
Education						
≤ Intermediate	51(71.8)	384(65.0)	χ^2 = 1.4,p = 0.499	170(66.4)	257(65.4)	χ^2 = 0.68,p = 0.712
Secondary	11(15.5)	107(18.1)		47(18.4)	67(17.0)	
University	9(12.7)	100(16.9)		39(15.2)	69(17.6)	
Nationality						
Non-Lebanese	8(11.3)	73(12.4)	χ^2 = 0.07,p = 0.792	21(8.2)	56(14.2)	**χ^2 = 5.4,p = 0.020**
Lebanese	63(88.7)	518(87.6)		235(91.8)	337(85.8)	
Region						
Bekaa	27(38.0)	158(27.1)	**χ^2 = 6.7,p = 0.035**	102(40.6)	76(19.5)	**χ^2 = 61.6,p < 0.001**
North	12(16.9)	69(11.8)		47(18.7)	34(8.7)	
South	32(45.1)	356(61.1)		102(40.6)	280(71.8)	
B. Cultivated land						
Number of irrigated lands	2.4 ± 3.4	1.9 ± 2.4	p = 0.206	2.3 ± 0.17	1.7 ± 0.12	**p = 0.007**
Total area of land (ha)	125.0 ± 30.9	142.8 ± 15.0	p = 0.690	124.3 ± 14.6	152.1 ± 21.2	p = 0.335
Irrigation interval (days)	10.8 ± 2.2	8.9 ± 0.58	p = 0.239	9.2 ± 0.81	8.8 ± 0.87	P = 0.777
Major crop			**χ^2 = 11.8,p = 0.008**			**χ^2 = 49.2,p < 0.001**
Potato	14(19.7)	113(19.1)		67(26.2)	58(14.8)	
Vegetables	8(11.3)	70(11.8)		40(15.6)	36(9.2)	
Citrus/Banana/Other tropical	33(46.5)	352(59.6)		107(41.8)	272(69.2)	
Other fruit trees	16(22.5)	56(9.5)		42(16.4)	27(6.9)	
Ability to locate your land (s)						
No	41(57.7)	277(46.9)	χ^2 = 3.0,p = 0.083	128(50.0)	184(46.8)	χ^2 = 0.63,p = 0.428
Yes	30(42.3)	314(53.1)		128(50.0)	209(53.2)	
C. Water source, method of irrigation and irrigation water use						
Water source						
River or spring	9(12.7)	21(3.6)	**χ^2 = 16.7,p = 0.024**	17(6.7)	12(3.1)	**χ^2 = 16.4,p = 0.010**
Canal	10(14.1)	70(11.8)		22(8.6)	57(14.5)	
Spring-River-Canal	2(2.8)	9(1.5)		4(1.6)	7(1.8)	
Spring-River-Well	1(1.4)	33(5.6)		15(5.9)	18(4.6)	
Well	46(64.8)	408(69.0)		182(71.1)	262(66.7)	
Well-Canal	3(4.2)	40(6.8)		6(2.3)	33(8.4)	
Buy Water	0	10(1.7)		6(2.4)	4(1.0)	
Well use						
Yes	50(100.0)	452(95.0)	χ^2 = 2.6,p = 0.153	197(96.6)	296(95.2)	χ^2 = 0.58,p = 0.445
No	0	24(5.0)		7(3.4)	15(4.8)	
Well depth (m)	131.0 ± 12.6	164.4 ± 5.7	**p = 0.002**	147.8 ± 8.1	165.2 ± 6.9	p = 0.106
Irrigation system						
Drip only	23(32.4)	203(34.3)	**χ^2 = 11.4,p = 0.023**	85(33.2)	138(35.1)	χ^2 = 4.4,p = 0.359
Sprinkler and drip	6(8.5)	78(13.2)		25(9.8)	56(14.2)	
Sprinkle only	12(16.9)	136(23.0)		64(25.0)	81(20.6)	
Surface and pressurized	10(14.1)	94(15.9)		40(15.6)	61(15.5)	
Surface only	20(28.2)	86(14.6)		42(16.4)	57(14.5)	
Flow meter						
No	68(95.8)	551(93.2)	χ^2 = 0.67,p = 0.609	246(96.1)	360(91.6)	**χ^2 = 5.0,p = 0.025**
Yes	3(4.2)	40(6.8)		10(3.9)	33(8.4)	
Energy type						
Fuel	38(74.5)	318(65.8)	χ^2 = 2.5,p = 0.474	158(76.0)	191(60.6)	**χ^2 = 23.2,p < 0.001**
Electricity	6(11.8)	60(12.4)		28(13.5)	36(11.4)	
Both	6(11.8)	99(20.5)		20(9.6)	84(26.7)	
Other	1(2.0)	6(1.2)		2(1.0)	4(1.3)	
Water cost($/ha/season)	393.1 ± 88.2	258.6 ± 16.2	p = 0.139	254.0 ± 34.1	374.8 ± 20.1	p = 0.322
Fuel cost($/ha/season)	529.8 ± 77.5	548.6 ± 22.6	p = 0.817	504.9 ± 39.0	570.8 ± 26.7	p = 0.155
Total cost ($/ha/season)	914.1 ± 96.5	793.3 ± 23.7	p = 0.228	**745.7 ± 43.3**	**849.3 ± 28.3**	**p = 0.038**
D. Irrigation management helps to:						
Increase the yield						
No	22(32.4)	46(8.0)	**χ^2 = 38.4,p < 0.001**	44(17.8)	24(6.2)	**χ^2 = 21.1,p < 0.001**
Yes	46(67.6)	532(92.0)		203(82.2)	362(93.8)	
Reduce the cost of irrigation						
No	22(33.3)	52(9.0)	**χ^2 = 34.8,p < 0.001**	45(18.1)	28(7.3)	**χ^2 = 17.6,p < 0.001**
Yes	44(66.7)	529(91.0)		203(81.9)	358(92.7)	
Reduce the cost of fuel						
No	19(30.6)	48(8.3)	**χ^2 = 29.6,p < 0.001**	40(16.7)	26(6.8)	**χ^2 = 15.4,p < 0.001**
Yes	43(69.4)	528(91.7)		200(83.3)	359(93.2)	
Reducing the cost of electricity						
No	17(28.3)	46(8.2)	**χ^2 = 24.1,p < 0.001**	39(16.8)	23(6.1)	**χ^2 = 17.9,p < 0.001**
Yes	43(71.7)	515(91.8)		193(83.2)	353(93.9)	
Willing to manage irrigation for your crops						

(*continued on next page*)

Table 3 (*continued*)

	Free application		Significance	Paid Application		Significance
	No	*Yes*		*No*	*Yes*	
No	34(52.3)	23(3.9)	$\chi^2 = 171.7, p < 0.001$	46(18.6)	9(2.3)	$\chi^2 = 51.3, p < 0.001$
Yes	31(47.7)	564(96.1)		201(81.4)	383(97.7)	

Continuous variables are presented as means with their standard deviations, whereas categorical variables are reported as frequencies and proportions (i.e. n (%))

regards to irrigation properties, the sources of the water, use of flow meters or irrigation control devices, energy type, and total cost were significantly associated with the use of paid smart irrigation mobile application. Participants who reported using canal water for irrigation were 3.7 times more likely to agree or strongly agree to use a paid smart irrigation mobile application for irrigation (OR = 3.7, 95% CI: 1.5,8.9, p = 0.004). Also, participants who reported using a flow meter or a controller for irrigation were 2.2 times more likely to agree or strongly agree to use a paid smart irrigation mobile application for irrigation (OR = 2.2, 95% CI: 1.1,4.7, p = 0.028). Additionally, using fuel and electricity for irrigation was associated with higher odds of using a paid smart irrigation mobile application compared to their counterparts (OR = 3.5, 95% CI: 2.0, 5.9, p < 0.001). Increased total cost was also associated with significantly higher odds of reporting "agree" or "strongly agree" to use a paid smart irrigation mobile application (OR = 1.00035, 95% CI: 1.00002, 1.0069, p = 0.039).

All views about irrigation management were significantly associated with the likelihood of using a paid smart irrigation mobile application. Participants who believed that irrigation management might help increase their crop yields were three times more likely to report "agree" or "strongly agree" to use a paid smart irrigation mobile application (OR = 3.3, 95% CI: 1.9, 5.5, p < 0.001). Similarly, participants who agreed or strongly agreed that irrigation management may help reduce irrigation, fuel, and electricity costs were significantly three times more likely to report "agree" or "strongly agree" to use a paid smart irrigation mobile application (OR = 2.8, 95% CI: 1.7, 4.7; OR = 2.8, 95% CI: 1.6, 4.7; OR = 3.1, 95% CI: 1.8, 5.3 respectively, p < 0.001 for all). Willingness to manage irrigation crops among study samples was significantly associated with higher odds of using a paid smart irrigation mobile application (OR = 9.7, 95% CI: 4.7, 20.3, p < 0.001).

3.2.6. *Multiple logistic regression model*

The following variables: age, nationality, region, number of irrigated lands, major crop, water source, flow meter use, energy type, total cost, and irrigation management variables were all included in the final multiple logistic model (Table 5). The analysis revealed that the likelihood to use a paid smart irrigation application in the study population was significantly associated with age (p < 0.05), region (p < 0.001), energy type (p = 0.004) and willingness to manage irrigation (p = 0.003). Participants belonging to the middle-age group (40–65 years) were significantly 56% less likely to agree or strongly agree to use a paid smart irrigation mobile application compared to younger age group, respectively (OR = 0.44, 95% CI: 0.20,0.95, p = 0.038). Additionally, participants residing in South Lebanon were 5.7 times more likely to agree or strongly agree to use a free smart irrigation mobile application compared to those living in Bekaa or North Lebanon (OR = 5.7, 95% CI: 2.1, 15.3, p < 0.001). Participants using fuel and electricity for irrigation were associated with a higher likelihood of using a paid smart irrigation mobile application compared to their counterparts (OR = 3.0, 95% CI: 1.4, 6.4, p = 0.004). After controlling for covariates, willingness to manage irrigation crops among the study sample remained significantly associated with higher odds of using a paid smart irrigation mobile application (OR = 10.3, 95% CI: 2.2,47.4, p = 0.003).

Interactions were performed between the educational level and region of residence of farmers in the present study sample (Table 6). The analysis revealed that participants residing in South Lebanon and with a university degree were more than four times more likely to agree or strongly agree to use a free smart irrigation mobile application compared to their counterparts (OR = 4.1, 95% CI: 0.99,17.3, p = 0.052, data not shown). Participants holding a university degree who reported using surface irrigation methods were less likely to agree or strongly agree to use a free smart irrigation mobile application compared to their counterparts (OR = 0.17, 95% CI: 0.05,0.62, p = 0.007). With regards to paid smart irrigation mobile application, analysis also revealed that participants residing in South Lebanon holding a university degree were three times more likely to agree or strongly agree to use of a paid smart irrigation mobile application compared to their counterparts (OR = 3.1, 95% CI: 1.6, 6.0, p = 0.001). There was no statistical significance for interactions between the use of paid smart irrigation mobile application and well depth or irrigation system types. Finally, regarding water source, participants using canals as their water source and those who had a higher total irrigation cost were more likely to agree or strongly agree to use of a paid smart irrigation mobile application compared to their counterparts (OR = 1.001, 95% CI: 1.0006.1.0011, p = 0.015). Similarly, participants with fruit crops with a higher total irrigation cost were more likely to agree or strongly agree to use a paid smart irrigation mobile application compared to their counterparts (OR = 1.0007, 95% CI: 1.0004, 1.0010, p = 0.015).

4. Discussions

This study revealed novel findings in terms of the willingness of farmers to adopt free smart irrigation technologies that require a minimal level of knowledge and skills. It focused on different farmers from several agro-climatic zones (sub-humid, semi-arid), and therefore various crops (citrus, banana, tropical fruits, other fruit trees, field crops, vegetables), irrigation systems, and educational background.

The cost of irrigation appeared to be a significant factor in willingness to pay. Survey results showed that farmers who pay more for their irrigations, and those who irrigate tree crops were more willing to pay for smart apps. Specifically, farmers who reported using a combination of surface and pressurized irrigation systems were seven times more likely to agree or strongly agree to use a free smart irrigation mobile application, which is attributed to the combined cost of surface water from canals and pumped groundwater, as well as to the area of the irrigated parcels.

The lack of a continuous electrical supply forces farmers in Lebanon to rely more on diesel, which is a more expensive option than oil. Fuel in Lebanon is also heavily taxed. A combination of a fixed irrigation interval, a 67% reliance on diesel adds to the high irrigation cost per irrigated area. With this high energy cost and a majority of farmers agreeing that they can reduce costs by managing their water, smart apps in the country have a promising future, particularly because 90% and 60% were willing to use a free and paid-for smart app, respectively. Although we did not find a direct relation between well depth and the willingness to use a paid smart app, it was evident that farmers who are paying more for their irrigation, and those who irrigate tree crops, are more willing to pay for such smart apps. We attribute this to a higher volume of water being pumped per year, which we could not verify due to the lack of adoption of flow measurements in the country by the farmers. The dependency of most farmers on deep wells for irrigation is the main reason for the high water and energy cost. As revealed in the survey results, the energy costs for irrigation in Lebanon (which ranged

Table 4
Simple and multiple logistic regressions exploring the association of socio-demographic characteristics, cultivated land and irrigation management of study sample with the likelihood to use of free smart irrigation mobile application.

	Simple logistic regression Free application OR (95% CI)	Multiple logistic regression Free application OR (95% CI)
A. Sociodemographic characteristics		
Age		
18–40 years	1.0	1.0
40–65 years	0.46(0.19,1.09), p = 0.080	0.32(0.09,1.2), p = 0.090
≥65 years	**0.31(0.12,0.84), p = 0.021**	1.4(0.23,9.2),p = 0.694
Education		
≤Intermediate	1.0	
Secondary	1.3(0.65,2.6),p = 0.464	
University	1.5(0.70,3.1),p = 0.304	
Nationality		
Non-Lebanese	1.0	
Lebanese	0.90(0.41,1.96), p = 0.792	
Region		
Bekaa	1.0	1.0
North	0.98(0.47,2.05), p = 0.963	0.71(0.09,5.8), p = 0.746
South	**1.90(1.10,3.3), p = 0.021**	**3.0(1.1,7.9),p = 0.025**
B. Cultivated land		
Number of irrigated lands	0.95(0.88,1.01), p = 0.122	
Total area of land (ha)	1.00(0.99,1.001), p = 0.692	
Irrigation interval(days)	0.98(0.94,1.02), p = 0.245	
Major crop		
Potato	1.0	
Vegetables	1.1(0.43,2.7),p = 0.863	
Fruit trees (e.g. citrus, banana, tropical)	1.0(0.55,1.9),p = 0.923	
Ability locate your land (s)		
No	1.0	
Yes	1.5(0.94,2.5),p = 0.085	
C. Water source, method of irrigation and irrigation water use		
Water source		
Spring River	1.0	1.0
Well	**3.8(1.6,8.8),p = 0.002**	0.95(0.16,5.5), p = 0.954
Canal	**3.0(1.1,8.3),p = 0.036**	1.8(0.21,15.6), p = 0.583
Well use		
No	1.0	
Yes	–	
Well depth (m)	1.003(1.000,1.006), p = 0.067	
Irrigation system		
Surface only	1.0	1.0
Sprinkler and drip	**2.2(1.1,4.2),p = 0.017**	1.2(0.40,3.8),p = 0.729
Sprinkle only	**3.2(1.2,8.5),p = 0.017**	2.0(0.47,8.2),p = 0.350
Surface and pressurized	**2.8(1.3,6.1),p = 0.008**	**7.0(1.7,29.6), p = 0.008**
Drip only	**2.3(1.04,5.3), p = 0.040**	2.4(0.58,9.9),p = 0.225
Flow meter		
No	1.0	
Yes	1.6(0.50,5.5),p = 0.416	
Energy type		
Fuel	1.0	
Electricity	1.2(0.48,2.9),p = 0.699	
Both	2.0(0.81,4.8),p = 0.135	
Other	0.72(0.08,6.1), p = 0.761	
Water cost($/ha/season)	**0.9994 (0.9988,0.9999), p = 0.024**	**0.9989 (0.9981,0.9997), p = 0.007**
Fuel cost($/ha/season)	1.000(1.000,1.001), p = 0.788	
Total cost($/ha/season)	1.000(0.999,1.000), p = 0.113	
D. Irrigation management helps to:		
Increase the yield		
No	1.0	1.0
Yes	**5.5(3.1,10.0), p < 0.001**	1.7(0.46,6.6),p = 0.409
Reduce the cost of irrigation		
No	1.0	1.0
Yes	**5.1(2.8,9.1),p < 0.001**	4.4(0.31,62.2), p = 0.271
Reduce the cost of fuel		
No	1.0	1.0
Yes	**4.9(2.6,9.0),p < 0.001**	0.32(0.02,4.3), p = 0.392
Reducing the cost of electricity		
No	1.0	1.0
Yes	**4.4(2.3,8.4),p < 0.001**	–
Willing to manage irrigation for your crops		
No	1.0	1.0
Yes	**26.9(14.2,51.0), p < 0.001**	**33.8(10.2111.4), p < 0.001**

Values are presented as Odds Ratio (95% CI). Estimates shown in bold are those that are statistically significant at $p < 0.05$.

from 470 to 778 $/ha) are much higher than those in the USA for example (which are at $153/ha) (USDA, 2018).

The fact that farmers who reported using a combination of surface and pressurized irrigation systems were seven times more likely to agree or strongly agree to use a free smart irrigation mobile application is attributed to the combined cost of surface water from canals and pumped groundwater, as well as to the extent of irrigated parcels. On average, the total fuel cost in $/ha of drip irrigation was 542.4 ± 29.7, for sprinkler and drip irrigation system was 778.7 ± 83.4, for surface, and pressurized irrigation was 538.7 ± 55.7, for sprinkler irrigation was 474.3 ± 46.9 and for surface irrigation was 474.7 ± 49.7. A significant association was found between fuel cost and irrigation system. Post-hoc analysis using the Bonferroni test revealed that participants using sprinkler and drip irrigation had significantly higher fuel costs compared to participants using any other method of irrigation (p = 0.001). Despite this, no significant association was found between the type of irrigation system used by the farmer and the willingness to use the smart app. Likewise, a significant association was found between water cost and irrigation systems. Post-hoc analysis using Bonferroni test revealed that participants using drip irrigation had significantly higher water cost compared to sprinkler and drip, sprinkler only and surface only (376.2 ± 28.2 $/ha vs. 183.3 ± 37.3 vs. 210.3 ± 35.8 vs. 217.2 ± 52.4 $/ha, p = 0.004, p = 0.005, and p = 0.013, respectively). It is also evident from the results that farmers who are using both drip and sprinkler irrigation are paying the largest cost of water per ha ($940/ha/yr), and more than 70% of these farmers, who happen to irrigated citrus and banana trees are willing to pay for a smart irrigation app. Education was not the major driver for adoption of this technology in Lebanon.

We attribute the willingness to pay for a smart app in the south region of the country to the following. The analysis showed a significant association between the geographical area and the major crops in the present study sample. In particular, a significantly ($p < 0.001$) higher proportion of study participants residing in the sub-humid South Lebanon (95.5%) had citrus, banana and other tropical fruits crops

Table 5
Logistic regressions exploring the association of sociodemographic characteristics, cultivated land and irrigation management of study sample with the likelihood to use of paid smart irrigation mobile application.

	Simple logistic regression Paid application OR (95% CI)	Multiple logistic regression Paid application OR (95% CI)
A. Sociodemographic characteristics		
Age		
18–40 years	1.0	1.0
40–65 years	**0.32(0.19,0.54),p < 0.001**	**0.44(0.20,0.95), p = 0.038**
≥65 years	**0.30(0.16,0.56),p < 0.001**	0.72(0.26,2.0), p = 0.538
Education		
≤Intermediate	1.0	
Secondary	0.94(0.62,1.44),p = 0.784	
University	1.17(0.75,1.81),p = 0.481	
Nationality		
Non-Lebanese	1.0	1.0
Lebanese	**0.54(0.32,0.91),p = 0.021**	0.65(0.26,1.6), p = 0.360
Region		
Bekaa	1.0	1.0
North	0.97(0.57,1.65),p = 0.913	1.5(0.32,6.8), p = 0.615
South	**3.7(2.54,5.35),p < 0.001**	**5.7(2.1,15.3), p < 0.001**
B. Cultivated land		
Number of irrigated lands	**0.90(0.83,0.98),p = 0.014**	1.09(0.94,1.2), p = 0.262
Total area of land (ha)	1.00(1.000,1.001), p = 0.351	
Irrigation interval(days)	0.99(0.96,1.03),p = 0.776	
Major crops		
Potato	1.0	1.0
Vegetables	1.04(0.59,1.8),p = 0.894	0.69(0.25,1.9), p = 0.470
Fruits (e.g. citrus, banana, tropical)	**2.3(1.5,3.5),p < 0.001**	0.57(0.17,1.9), p = 0.361
Ability locate your land (s)		
No	1.0	
Yes	1.1(0.83,1.6),p = 0.428	
C. Water source, method of irrigation and irrigation water use		
Water source		
Spring River	1.0	1.0
Well	2.0(0.95,4.4),p = 0.067	–
Canal	**3.7(1.5,8.9),p = 0.004**	–
Well use		
No	1.0	
Yes	0.70(0.28,1.7),p = 0.447	
Well depth (m)	1.001(1.000,1.003), p = 0.108	
Irrigation system		
Surface only	1.0	
Sprinkler and drip	1.2(0.74,1.9),p = 0.466	
Sprinkle only	1.6(0.89,3.1),p = 0.112	
Surface and pressurized	0.93(0.56,1.6),p = 0.791	
Drip only	1.1(0.64,2.0),p = 0.685	
Flow meter		
No	1.0	1.0
Yes	**2.2(1.1,4.7),p = 0.028**	1.00(0.40,2.5), p = 0.993
Energy type		
Fuel	1.0	1.0
Electricity	1.1(0.62,1.8),p = 0.822	1.2(0.48,3.0), p = 0.687
Both	**3.5(2.0,5.9),p < 0.001**	**3.0(1.4,6.4), p = 0.004**
Other	1.6(0.30,9.1),p = 0.564	0.83(0.13,5.6), p = 0.849
Water cost($/ha/season)	1.000(1.000,1.001), p = 0.323	
Fuel cost($/ha/season)	1.000(1.000,1.001), p = 0.156	
Total cost($/ha/season)	**1.00035 (1.00002,1.00069), p = 0.039**	1.000(1.000,1.001), p = 0.230
D. Irrigation management helps to:		
Increase the yield		
No	1.0	1.0
Yes	**3.3(1.9,5.5),p < 0.001**	0.87(0.25,3.0), p = 0.825
Reduce the cost of irrigation		
No	1.0	1.0
Yes	**2.8(1.7,4.7),p < 0.001**	0.15(0.01,3.0), p = 0.218
Reduce the cost of fuel		
No	1.0	1.0
Yes	**2.8(1.6,4.7),p < 0.001**	13.9(0.74,262.1), p = 0.079
Reducing the cost of electricity		
No	1.0	1.0
Yes	**3.1(1.8,5.3),p < 0.001**	–
Willing to manage irrigation for your crops		
No	1.0	1.0
Yes	**9.7(4.7,20.3),p < 0.001**	**10.3(2.2,47.4), p = 0.003**

Values are presented as Odds Ratio (95% CI). Estimates shown in bold are those that are statistically significant at $p < 0.05$.

compared to those with vegetables (3.5%) and other fruit trees (1.0%), and a significantly greater proportion of participants residing in North Lebanon (60.5%) had potato crops compared to their counterparts. In the semi-arid Bekaa region, a larger number of participants had potato (42.6%), fruit trees (31.1%) followed by vegetables (26.3%). The analysis also showed, while there is a significant association between region and education level of Lebanese farmers in the present study sample, education alone was not a significant driver for adoption. For example, despite that 48% of farmers in the Bekaa had a secondary school education or higher, only 42% agreed to pay for a smart app, as compared to 73% of farmers in the South, of whom only 30% had secondary education or higher. The fact that two-thirds of the study sample had only intermediate school education may explain why only 52% of the farmers said they were able to locate their land on Google Maps.

5. Conclusion

This study reveals novel findings in terms of the willingness of farmers to manage their farm water applications and adopt free smart irrigation technologies that will help them do so. It can guide as to the profile of farmers that can be targeted when deploying such apps. Our findings indicate that farmers in Lebanon relate better irrigation management to improved crop yields, reduced energy and fertilizers input, which provides hope for improving economic water productivity in agriculture. Overall, the results of the survey were promising for the future of agricultural water management in a developing and medium to low-income country. Farmers, in general, are willing to adopt smart irrigation technologies, with younger farmers being attracted the most. To our knowledge, this study is the first national study in the Middle East and North Africa (MENA) region that targets the willingness of farmers to adopt smart apps in irrigation management and, therefore, neighboring countries would benefit from these results until similar studies are conducted in the region. We showed that while Lebanese farmers do not adequately measure or know their crop water requirements and the amount of water applied, they seem to be willing to adopt better irrigation management techniques when guided, especially in the form of a

Table 6
Logistic regressions exploring the association of interactions sociodemographic characteristics, irrigation system and water/fuel cost with the likelihood to use of free (paid) smart irrigation mobile application.

	Free application	Paid application
	Simple logistic regression OR (95% CI)	
Governorate		
Bekaa/Intermediate or less (Reference)	1.0	1.0
North *Secondary	0.95(0.11,7.8), p = 0.962	0.73(0.18,3.0), p = 0.664
North *University	0.27(0.02,3.0), p = 0.290	1.5(0.13,16.3), p = 0.755
South *Secondary	1.5(0.59,3.9), p = 0.389	1.5(0.87,2.7), p = 0.137
South *University	**4.1(0.99,17.3), p = 0.052**	**3.1(1.6,6.0), p = 0.001**
Irrigation system		
Sprinkler/Intermediate or less (Reference)	1.0	1.0
Drip*Secondary	0.61(0.24,1.5), p = 0.284	0.62(0.32,1.2), p = 0.151
Surface irrigation*Secondary	0.97(0.22,4.3), p = 0.96	0.45(0.18,1.1), p = 0.090
Drip*University	1.5(0.51,4.2), p = 0.468	1.3(0.70,2.3), p = 0.431
Surface irrigation*University	**0.17(0.05,0.62), p = 0.007**	0.26(0.07,1.0), p = 0.056
Well depth		
Well depth*Fuel cost	1.000(1.000,1.000), p = 0.154	1.000(1.000,1.000), p = 0.432
Well depth*Water cost	1.000(1.000,1.000), p = 0.708	1.000(1.000,1.000), p = 0.129
Well depth*Total cost	1.000(1.000,1.000), p = 0.517	1.000(1.000,1.000), p = 0.330
Water source		
Spring River (reference)	1.0	1.0
Well* Total cost	1.000(0.999,1.000), p = 0.854	1.000(1.000,1.000), p = 0.593
Canal* Total cost	1.000(0.999,1.001), p = 0.785	**1.001(1.0006,1.0011), p = 0.015**
Major crop		
Potato(reference)	1.0	1.0
Vegetables* Total cost	1.000(0.999,1.000), p = 0.470	1.000(0.999,1.000), p = 0.787
Fruits* Total cost	1.000(0.999,1.000), p = 0.561	**1.0007(1.0004,1.0010), p < 0.001**

Values are presented as Odds Ratio (95% CI). Estimates shown in bold are those that are statistically significant at $p < 0.05$.

mobile smart irrigation application. Although this is a national survey spanning only farmers in the country of Lebanon, we strongly believe that our survey results can be extended to other countries in the MENA region where farmers in such region share similar culture and persona, which reflect fundamental similarities in agriculture and irrigation practices. We believe the results can guide stakeholders and private sector interested in digital technologies in agriculture in areas in which farmers have similar educational profile, plant similar crops, rely mainly on groundwater for their irrigations, and use similar irrigation methods. It is anticipated that academicians, researchers, policy makers, and public officials will frequently refer to these results in comparable settings. We showed, in this study, how complicated the interlinkages between demography, age, region, irrigation system types, water source, and water costs are, and how these factors affect the choice of adopting smart technology. Most farmers in Lebanon are willing to adopt a free app, but when it comes to payment, the situation gets more complicated as affordability, and the added value of irrigation management, are not always clear to the farmers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval and consent to participate

This article contains data collected from interviewing participants after obtaining their written consent. The study has been approved by the Institutional Review Board (IRB) at the American University of Beirut (AUB).

Consent for publication

Not applicable.

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