International Labour Organization

Climate-Smart and Water-Efficient Agriculture in Lebanon:

Enhancing Productivity, Sustainability, and Decent Work

ISBN: 9789220429723 (web PDF)
DOI: https://doi.org/10.54394/CJCH9765

Foreword

This report entitled "Climate-Smart and Water-Efficient Agriculture in Lebanon: Enhancing Productivity, Sustainability, and Decent Work" was developed by the International Labour Organization (ILO) under the project "Building Inclusive Markets and Decent Work for Syrian Refugees and Lebanese Host Communities" (BOUZOUR), supported by the Swedish International Development Cooperation Agency (Sida).

As climate change and water scarcity increasingly impact agricultural sustainability, Lebanese farmers face rising irrigation costs, over-irrigation, and polluted water sources that threaten productivity. Additionally, many farmers rely on wells to pump groundwater for irrigation, leading to sinking groundwater levels, which is not being replenished as quickly as before due to changing weather patterns. As these levels drop, farmers are forced to dig deeper, creating a vicious cycle that further depletes water resources.

As part of its broader effort to promote decent work and sustainable economic opportunities for Syrian refugees and Lebanese host communities, the BOUZOUR project promotes climate-resilient and water-efficient practices. Within this framework, it piloted climate-smart solutions and water-efficient technologies to demonstrate the business case for adopting sustainable agricultural practices.

This report documents the design, implementation, and outcomes of the Climate-Smart Agriculture Pilot Project, conducted across fifteen farms in Lebanon. The pilot aimed to assess the environmental, economic, and social impacts of sensor-based irrigation and fertigation technologies, capture farmer experiences, and generate evidence-based recommendations for scaling up these innovations.

The study compares sensor-based (SB) irrigation and fertigation systems with traditional farmer-based (FB) practices across the fifteen pilot farms, which covered a range of crops including leafy vegetables, tomatoes, onions, peaches and avocados under both greenhouse and open-field conditions. The objective was to determine whether SB systems could maintain or improve crop productivity while reducing inputs such as water, fertilizer, and energy, thereby enhancing farm profitability and climate resilience. The report summarizes data collected between January and August 2025.

The ILO partnered with SmartLand Agri, a Lebanese agri-tech company specializing in sensor-based irrigation and fertigation systems to install and monitor the climate smart agricultural solutions. Fieldwork and data collection were led by Dr. Yolla Ghorra Chamoun, Associate Professor at the University of Saint Joseph (USJ), with the active participation and cooperation of the participating farmers.

This report presents and analyses the field results, drawing insights from the consultant, workers, employers, and SmartLand Agri across different regions. It was drafted under the BOUZOUR project by Bahjat Loutfi, and the assessment was coordinated and technically supported by Luana Ayala and Bahjat Loutfi, based on technical reports and data compiled by Dr. Yolla Ghorra Chamoun, with valuable contributions from Nadja Nutz and Mette Grangaard Lund.

Table of Contents

Foreword ... **1**

Executive Summary ... **2**

Introduction ... **3**

1. Pilot Design and Implementation Overview ... **5**

1.1. Sensor-Based Technologies for Climate-Smart Farming ... 5

1.2. Cooperatives and Farmers Selection ... 6

1.3. Installation and Experimental Design ... 6

1.4. Geographic Scope and Crop Diversity ... 8

1.5. Soil and baseline practices ... 8

1.6. Data collection and indicators ... 8

2. Results: Sensor-Based vs. Farmer-Based Systems ... **9**

2.1 Agricultural Productivity ... 9

Improved Growth and Maturation ... 9

Improved Yield Performance while reducing input use ... 10

Produce Quality ... 11

2.2 Environmental Efficiency and Climate Resilience ... 11

Water Use Efficiency ... 12

Fertilizer Efficiency ... 13

Soil Health ... 13

Energy Use and Greenhouse Gas Emissions ... 13

2.3 Labour Efficiency ... 14

2.4 Cost-Effectiveness and Sustainability ... 14

3. Farmer Success Stories and Adoption ... **15**

4. Key Lessons from the pilot ... **22**

4.1. Improving efficiency ... 22

4.2. Implementation Challenges and Enabling Factors ... 22

Conclusion ... **29**

Executive Summary

The Climate-Smart Agriculture Pilot Project, implemented by the International Labour Organization (ILO) with support from Sida, tested sensor-based precision irrigation and fertigation across 15 farms in Lebanon. The project addressed key challenges facing Lebanese agriculture: water scarcity, rising fertilizer costs, and climate variability, while contributing to the ILO's objective of promoting green and decent jobs in the agriculture.

The pilot aimed to promote resource-efficient farming, reduce water and fertilizer use, improve labour productivity, enhance productivity, and assess economic feasibility under local conditions.

Table 1: *Key Performance Indicators and Outcomes of Sensor-Based Farming Across Pilot Farms*

Dimension	Indicator	Average Result	Highlight
Productivity	Yield & quality	+6–20%	+16% Class A produce
Environmental	Water savings Fertilizer savings GHG emissions	22–40% 50–67% −50–60%	Up to 50% in orchards Without yield loss Lower pumping & fertilizer
Labour	Labour efficiency	18–25 h saved	Less field monitoring
Economic	Return on investment	14–22%	Payback in 1–3 cycles

The uptake of sensor-based farming improved when training, technical support, and cooperative engagement were available. The pilot showed clear gains in water use, fertilizer efficiency, and crop quality, but results were shaped by several constraints. Upfront costs remained a barrier for many farms (approximately $600 per hectare per unit). Limited extension capacity, uneven technical skills, and unstable digital connectivity affected real-time use of the system. All farms received systems that included both irrigation and fertigation functions, but they relied mainly on the irrigation side. The fertigation function was underused because EC sensors measure overall salinity rather than specific nutrients, and interpreting EC trends requires scientific skills and close follow-up. Farms that actively used both functions with regular technical support achieved the strongest results.

Overall, the pilot confirms that precision irrigation is viable in Lebanon but not automatically transformative. Wider uptake will depend on affordability, context-specific adaptation, and continued training and maintenance support. If scaled nationally, this approach could save millions of cubic meters of water, lower dependence on fertilizer imports, and enhance resilience to climate shocks.

Introduction

Within the framework of the Building Inclusive Markets and Decent Work for Syrian Refugees and Lebanese Host Communities (BOUZOUR) project, the ILO is working to strengthen agricultural productivity, market access, and working conditions in Lebanon. The goal is to create more and better jobs for both Lebanese host communities and Syrian refugees.

As part of this broader intervention strategy, a pilot initiative was launched to support the uptake of climate-smart and water-efficient technologies among small and medium sized farmers. On-farm trials were conducted to test sensor-based irrigation and fertigation systems, demonstrating how digital agriculture solutions can enhance productivity, improve labour efficiency, and reduce environmental impacts and production costs.

Agriculture remains a cornerstone of rural employment and food security in Lebanon, yet farmers face multiple challenges that threaten productivity, resilience and fair market participation. Water scarcity, driven by over-reliance on groundwater and declining rainfall, is a primary constraint. Traditional irrigation practices, often based on intuition rather than data, result in water waste and soil degradation. Soil degradation leads to increased costs in other inputs, such as fertilizers. Rising input costs for fertilizers, seeds, and fuel, combined with limited access to credit, further reduce competitiveness. Many small and medium farmers lack both capital and technical awareness to invest in modern systems, perceiving them as costly or complex. Climate variability intensifies these challenges through droughts, heatwaves, and crop diseases, directly affecting yields and income stability.

In this context, data-driven irrigation and fertigation systems offer a cost-effective opportunity to apply the right input, at the right time, and in the right amount, improving efficiency while safeguarding resources. By promoting the use of these technologies, the initiative can support a just transition in agriculture, fostering green job creation, environmental sustainability, and safer, higher-value work opportunities for Lebanese and Syrian agricultural workers alike. The project applies a market systems development approach, engaging agritech providers, cooperatives, and farmers to strengthen access, affordability, and long-term viability of these solutions.

A total of 15 pilot farms participated, representing diverse production systems, greenhouse horticulture and open-field orchards, and crops such as leafy vegetables, tomatoes, onions, peaches, avocados, and cherries. The pilot was implemented in Akkar and the Bekaa Valley through five agricultural cooperatives and one private agribusiness company acting as a buyer and farm network coordinator. Activities combined hands-on workshops, field coaching, and real-time monitoring to integrate smart agriculture practices into daily operations.

The objectives of the pilot were:

A. Provide farmers with practical demonstrations of sensor-based irrigation and fertigation systems to build trust and familiarity with the technology;
B. Measure impacts on water savings, crop growth, yields, quality, and input efficiency compared to traditiona farmer-based practices;
C. Generate evidence on economic, environmental, and social benefits to inform future scaling and adopting strategies across Lebanon’s agriculture sector.

Trials were conducted in phases aligned with regional cropping calendars to capture region-specific results and implementation challenges.

Box 1. What is market systems development?

A market system is made up of the many ‘supporting functions’ and ‘rules’ that shape how well a market works for poor women and men. Supporting functions – such as information, skills, infrastructure, finance and access to markets – inform, support and shape a market. The ‘rules’ – such as policies, business standards, social norms and culture – guide daily attitudes and behaviours within the market. The market systems development approach aims to address the underlying causes of problems that exist in the market, which means understanding and tackling the issues that create problems in the first place. It focuses on selected markets (be they commodities, like the soybean value chain, or whole sectors like construction) to address specific decent work deficits. To achieve this, projects invest in promising innovations, involving existing public and private stakeholders that can spur more inclusive market growth.

The objective of market systems development projects is to generate an impact that is both:

Sustained
Projects achieve lasting behaviour change with public and private actors by aligning interventions to stakeholders’ incentives and capacity. Impact continues long after interventions end because actors see organisational value in continuing the new way of working;

Scaled
Since constraints to industry growth are removed, change is replicated and mainstreamed across the sector – rather than being only confined to the actors that the project directly works with.

1. Pilot Design and Implementation Overview

The pilot intervention assessed the feasibility, effectiveness, and scalability of climate-smart irrigation and fertigation systems as a business model for small and medium-scale farmers. Implemented in partnership with Smart Land Agri, fifteen farms were equipped with sensor-based systems monitoring soil moisture, nutrient levels, and local climatic conditions. The systems were integrated with mobile applications enabling real-time visualization and remote control. Farmers received training, technical support, and continuous follow-up to build farmer capacity and document lessons for future scale-up.

1.1. Sensor-Based Technologies for Climate-Smart Farming

Agricultural sensors provide real-time data for precise irrigation, nutrient management, and crop monitoring. The system used in the pilot consists of three main parts: a sensor board placed in the field that measures soil moisture, nutrients, and environmental conditions; a central control unit that receives the data and automatically adjusts irrigation and fertigation; and a mobile/online application that allows farmers to view readings, receive alerts, and manage the system remotely. Together, these components turn real-time field data into automated irrigation and nutrient decisions.

Soil moisture sensors are central to smart irrigation systems. They measure the amount of water available in the soil at different depths, enabling farmers to irrigate according to the crop's actual needs.

Nutrient sensors, including electrical conductivity (EC) help monitor the concentration of key nutrients in the soil or irrigation water. By tracking these levels, farmers can apply fertilizers more accurately and only when needed.

Environmental sensors, including weather stations and devices that measure temperature, humidity and rainfall, help farmers to understand the effect of weather and microclimate on crop growth and water needs.

The pilot also used sensor technology developed by **Groinn**, a Spain-based agri-tech company specializing in advanced calibration and data analytics for precision agriculture. Field deployment and integration were carried out by **SmartLand Agri** in collaboration with the **Lebanese Agricultural Research Institute (LARI)**, which conducted comparative laboratory testing to verify sensor accuracy for soil pH, EC, and nutrient concentrations.

(© ILO, 2025)

In-field installation during pilot trials. A Smart Land Agri sensor board placed in the field measures soil moisture, nutrients, and environmental conditions. A central control unit receives data and automatically adjusts irrigationand fertigation.

(© ILO, 2025)

1.2. Cooperatives and Farmers Selection

Cooperatives served as the main entry points for farmer's engagement and knowledge sharing. Selection was based on institutional strength, agricultural relevance, and infrastructure readiness. Eligible cooperatives were legally registered, active for at least one year, and composed of at least fifteen members in areas of significant agricultural activity. Additional factors included membership size, women's participation, compliance with labour laws, willingness to collaborate, and crop compatibility with project objectives. Connectivity, access to irrigation water, and use of drip systems were also assessed. Priority went to cooperatives demonstrating openness to technology and a strong record of community participation to maximize the impact and scalability of project's outcomes.

Individual farmers were identified through these cooperatives using complementary criteria. Participants were at least 18 years old, owned or leased land, and adhered to labour standards, including the elimination of child labour. Candidates required basic infrastructure such as drip irrigation and internet access for real-time data transmission. Preference was given to greenhouse farmers and open-field farmers cultivating orchards or vegetables within the October–August season. Social inclusion was emphasized, targeting women (29% female participants) and youth farmers with strong community standing and willingness to share experiences.

This selection approach combined social, economic, and technical dimensions to engage farmers capable of maintaining the systems and demonstrating their potential within their communities.

1.3. Installation and Experimental Design

Once selected, the Smart Land systems were installed using a standardized protocol, with greenhouse plots prioritized. Farmers were trained on operation, maintenance, and use of the mobile application, followed by monthly visits to provide technical support and ensure proper system performance. Baseline soil analyses conducted by LARI assessed fertility and informed sensor calibration, including soil texture, organic matter, pH, electrical conductivity, and key nutrients (N, P, K, Ca, Mg). Corrective actions aligned the sensor-based and farmer-based plots under comparable starting conditions, and all sensors were field-calibrated against laboratory benchmarks to ensure measurement accuracy.

Each participating farmer managed two adjacent plots: one equipped with the **sensor-based system (SB)** and another under **traditional farmer-based practices (FB)**. This design enabled direct, within-farm comparisons across multiple indicators of resource efficiency, productivity, environmental impact, social
and economic performance.

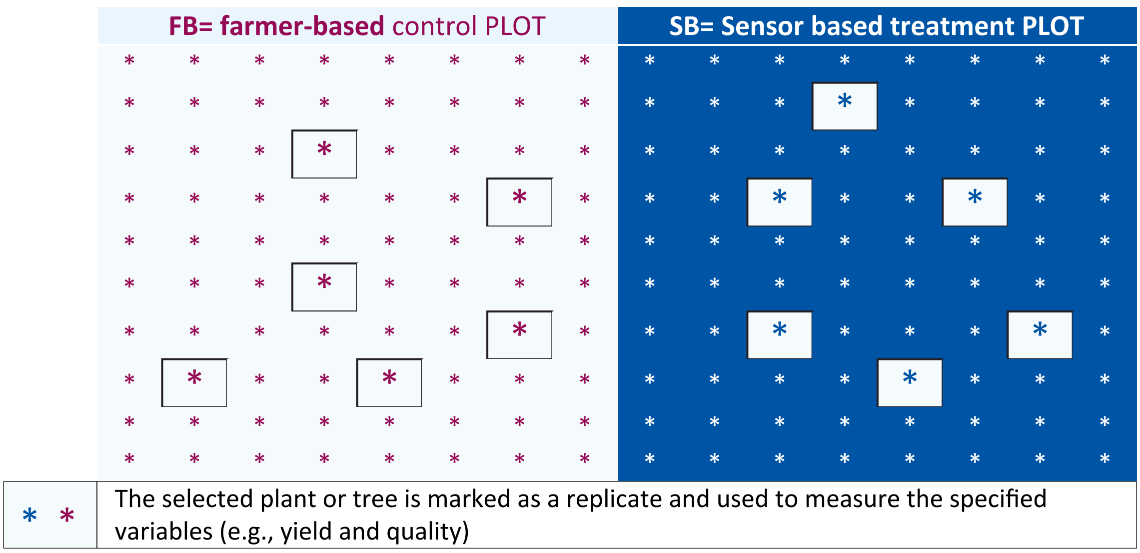


Figure 2: *Side-byside comparison design*

Table 2: *Overview of selected farmers and field characteristics*

Farm	Gender	District	System	Crop	FB Plot	SB Plot
1	Male	Akkar	Open Field	Avocados	1.0 ha	0.2 ha
2	Mixed	Akkar	Greenhouse	Leafy Greens	4 GH	2 GH
3	Male	Akkar	Greenhouse	Leafy Greens	5 GH	3 GH
4	Male	Akkar	Open Field	Apples	0.8 ha	0.2 ha
5	Male	Akkar	Greenhouse	Onions	5 GH	2 GH
6	Female	Zahle	Open Field	Cherries	0.5 ha	0.2 ha
7	Female	Zahle	Open Field	Tomatoes	0.8 ha	0.2 ha
8	Female	West Bekaa	Greenhouse	Lettuces	2 GH	2 GH
9	Mixed	Zahle	Greenhouse	Baby Rocca	4 GH	3 GH
10	Male	Zahle	Greenhouse	Tomatoes	8 GH	4 GH
11	Male	Zahle	Greenhouse	Lettuces	25 GH	5 GH
12	Male	West Bekaa	Open Field	Peaches	0.4 ha	0.2 ha
13	Male	West Bekaa	Open Field	Peaches	0.8 ha	0.4 ha
14	Male	West Bekaa	Open Field	Peaches	1.5 ha	0.4 ha
15	Male	West Bekaa	Open Field	Onions	0.3 ha	0.15 ha

1.4. Geographic Scope and Crop Diversity

Fifteen pilot farmers were selected across Akkar and the Bekaa Valley capturing a range of agroecological conditions and farming systems.

- **West and Central Bekaa (~900–1000 m)**: Semi-arid Mediterranean climate, with hot dry summers (~30 °C highs) and cool wet winters. Rainfall averages ~600 mm, concentrated November–March. Summer droughts necessitate irrigation, and in 2025 a dry winter and spring required early irrigation.

- **Akkar (~600–700 m)**: Slightly more temperate and humid, with ~800 mm annual rainfall and milder summers, but still prone to winter frost and snow. In March 2025, an unusual late snowstorm and week-long frost caused severe fruit-set losses. Farmers also faced higher winter humidity, which increased disease pressures.

The fifteen pilot farmers represented a diverse range of crop types, and farming systems. Nine farmers focused on annual crops, with seven cultivating in greenhouses and two in open fields, while six managed perennial crops in open-field plots. Crops included vegetables (leafy greens, tomatoes, onions), stone fruits, apples, and avocados.

The group included five women and twelve men farmers, distributed among 15 farms mostly under 50 years of age, with several younger farmers particularly motivated to explore innovative practices. Farmers were linked to five cooperatives and one agribusiness, ensuring strong community engagement and facilitating knowledge sharing. Notably, most farmers, climate smart solutions for the first time. Awareness of smart irrigation was low, confirming the relevance of the pilot and the need for introductory training to enable future adoption.

1.5. Soil and baseline practices

Soils across the pilot farms were predominantly clay, with only one sandy clay exception in Kobayat. Baseline analyses showed neutral to alkaline pH and high calcareous content, limiting phosphorus availability. Excessive fertilizer use was common, particularly nitrogen, causing nutrient imbalances, especially magnesium accumulation in greenhouse. Overall, the baseline showed a tendency toward both over-irrigation and excessive nutrient application, reflecting the low perceived cost of water and a "more is better" approach to inputs.

1.6. Data collection and indicators

Farmers collected data in both SB and FB plots, providing insights into how precision irrigation, optimized fertigation, and improved soil management contribute to higher yields, resource efficiency, and climate resilience. Data was collected from November 2024 to August 2025, covering winter and summer cycles. Farmers retained ownership of their data and produce, with monthly technical visits ensuring maintenance and validation. Quantitative data was complemented by qualitative feedback from farmers and cooperatives to inform farmer decision-making and targeted information campaigns demonstrating the practical advantages of climate-smart solutions and encouraging wider adoption among farmers.

Indicators were structured around five domains:

1. **Agricultural productivity:** yield and crop quality (weight, diameter, Brix).
2. **Climate resilience:** water and fertilizer use efficiency.
3. **Labour efficiency:** time and effort invested in irrigation and fertilization.
4. **Environmental sustainability:** soil health and reduced chemical inputs.
5. **Economic performance:** input costs, operational savings, and return on investment.

Implementation outcomes varied among the 15 participating farms. Not all farms used both the irrigation and fertigation functions or were able to fully operate them. Twelve farms used sensor-based irrigation, collecting water-related and crop management data, with the type and extent of observed benefits differing by sensor deployment. Five farms used both moisture and nutrient sensors, allowing monitoring of soil moisture and nutrient status. Two farms encountered persistent internet connectivity issues, which disrupted sensor data transmission and functionality. As such, the findings should be viewed as indicative rather than definitive. They are derived from verified datasets within varying operational conditions, and while they demonstrate clear trends, some degree of uncertainty remains due to differences in sensor performance, calibration, data continuity, and farm management practices.

▶ 2. Results: Sensor-Based vs. Farmer-Based Systems

This chapter presents the main results comparing SB and FB management systems. It focuses on changes in productivity, input efficiency, environmental performance, and labour outcomes across pilot farms, highlighting how datadriven irrigation improves water and fertilizer management, complements farmer expertise, and enhances crop yieldsand work efficiency. Workshops and field coaching introduced farmers to the climate-smart system. Early doubts about sensor reliability declined as field data confirmed farmer observations and exposed inefficiencies in irrigation and fertilization.

2.1. Agricultural Productivity

The adoption of SB irrigation and fertigation systems led to measurable improvements across key dimensions of agricultural productivity. Field observations and trials showed consistent gains in plant growth, yield performance, and produce quality compared with traditional FB practices. The following sections summarize the main results.

▶ Improved Growth and Maturation

SB irrigation and fertigation helped crops grow more vigorously and mature faster, without disrupting their natural development cycles.

Perennial crops like peaches and avocados, maintained the same flowering and harvest timings as under traditional FB management, confirming that the technology works in harmony with natural crop development. However, SB-managed plants grew more vigorously. For example, young avocado trees in Kobayat grew nearly 0.5 m taller by midsummer compared to those under FB management, indicating that SB management helped reduce water stress.

Annual greenhouse crops also benefited from faster growth. Lettuce reached marketable size five days earlier, and cabbage matured six days sooner than under FB practices. Even small improvements of 5-10% in crop cycles can help farmers reach markets earlier and potentially increase the number of harvests per year.

Overall, these findings suggest that precision irrigation allows plants to use water and nutrients more efficiently, leading to healthier growth, better fruit development, and higher-quality produce.

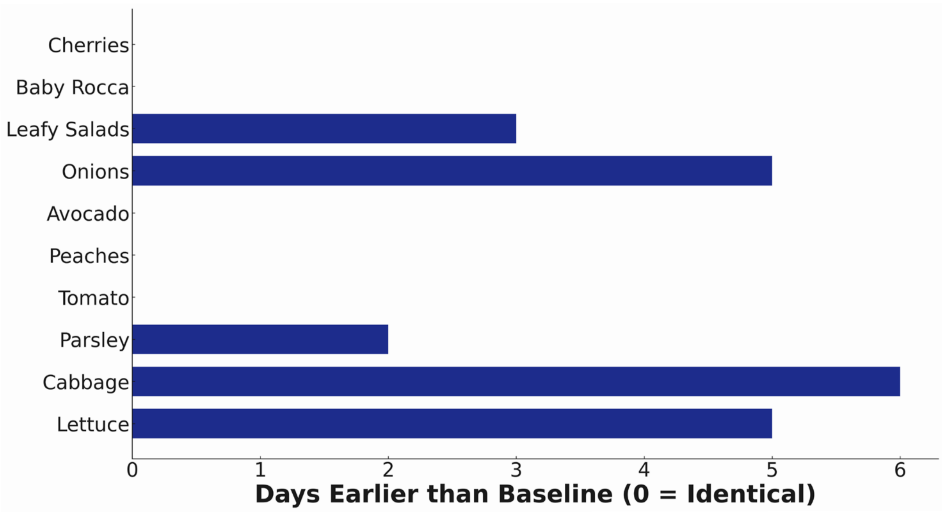


Figure 3: *Advancement in growth stage by crop*

▶ Improved Yield Performance while reducing input use

Across most crops, farms using SB management achieved the same or higher yields than those using traditional FB management. Even while using fewer inputs, such as water and fertilizer (see section 2.2). On average, yield increased by **17%**, with gains ranging from 8% for leafy vegetables to as much as 30% for stone fruits.

In orchards, results were more variable due to the natural alternation of high and low yielding years. Still, **peach orchards** managed under SB consistently produced at the higher end of the normal range (**25–30 kg/tree vs. 15–30 kg/tree** under FB). **Avocado trees** showed enhanced vegetative growth, indicating strong potential for higher fruit yield and size in the next seasons.

Table 3: *Yield increase under SB versus FBmanagement*

Crop	Location	Yield Increase	Notes
Lettuce	Akkar	+23%	26,000 vs 21,000 heads/ha
Avocado	Akkar	+20%	Enhanced vegetative growth
Peaches	Bekaa	+10–30%	Variable due to frost/biennial bearing
Parsley	Akkar	+17%	140,000 vs 120,000 bunches/ha
Cabbage	Akkar	+15%	23 vs 20 tons/ha
Tomato	Bekaa	+8%	35tons/ha to 37.5 tons/ha
Onions	Akkar	+8%	30tons/ha to 32.4 tons/ha

▶ Produce Quality

SB irrigation and fertigation significantly improved produce quality, increasing the share of top-grade (Class A) products by an average of 26%. Crops grown under SB management were consistently larger, sweeter, and more uniform in size and colour compared to those under traditional FB practices.

Leafy vegetables showed the strongest gains with up to 40% more Class A produce, while fruit crops such as cherries and peaches recorded fruit sizes 20-44% larger and about 0.5 °Brix higher sugar content. In one Akkar greenhouse, nearly all vegetables qualified as Class A under SB, compared to 80% under FB. Baby Rocca was excluded from the comparison because both systems already produced 100% Class A. No measurable improvement could be calculated.

These improvements directly enhance farmers' incomes by boosting market prices, improving grading outcomes, and reducing post-harvest losses. These results confirm that precision irrigation can improve both crop quality and profitability.

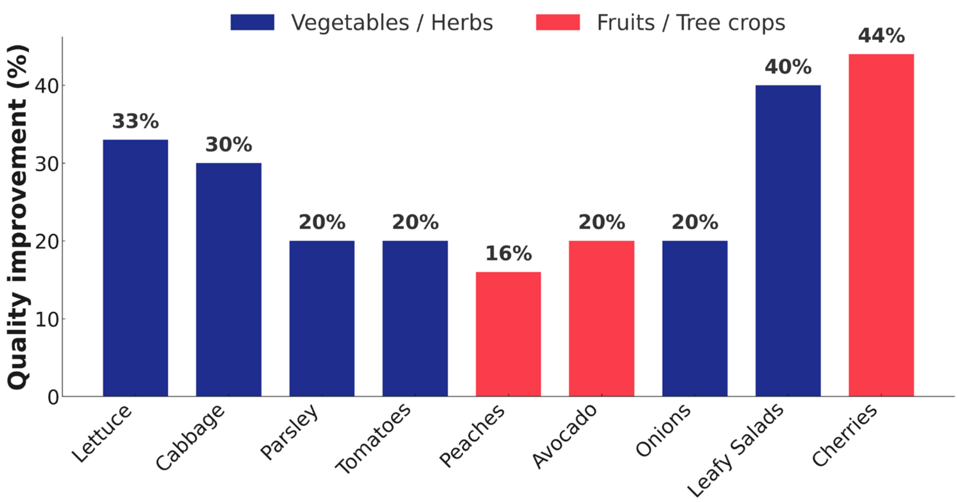


Figure 4: *Produce quality improvement by crop (averaged)*

2.2. Environmental Efficiency and Climate Resilience

SB irrigation and fertigation significantly improved environmental efficiency and crop resilience, achieving major reductions in water, fertilizers, and energy use. They also enhanced soil health and reduced greenhouse gas emissions, highlighting the potential of precision agriculture to drive sustainable, climate-smart farming in Lebanon's increasingly water-scarce conditions.

▶ Water Use Efficiency

The most striking outcome of the trial was the substantial water savings achieved with SB irrigation. On average, SB farms used **38% less water** than traditional FB systems, with savings ranging from **14% in baby-leaf greenhouses to nearly 60% in peach orchards.** These savings were achieved without any signs of crop stress, as irrigation was applied only when soil sensors indicated a real need.

In some cases, SB irrigation improved both water efficiency and productivity at the same time. Lettuce production consumed 41% less water while delivering 23% higher yields, and avocado orchards halved their irrigation volumes without showing any stress symptoms. Across all trials, the sensor-based system consistently reduced water use by 14–47% in greenhouses and 13–60% in orchards, while yields remained stable or even increased by up to 20%.

Sensors helped maintain soil moisture within an optimal range (around 20–25%), preventing both over-irrigation and drought stress. This precise control supports healthier root systems and helps farmers cope with increasingly unpredictable rainfall patterns.

Crop-specific results:

. **Leafy greens (lettuce, cabbage, parsley):** Water use was reduced by approximately 40% across crops. For lettuce specifically, irrigation dropped from 24.5 L/head (FB) to 10.5 L/head, while delivering higher yields of 15–23% under sensor-based irrigation.
. **Onions:** Irrigation reduced by 42%, while yield increased by 8%, cutting water applied per ton of onions by ~46%.
. **Tomatoes:** Required ~41% less water under SB irrigation while achieving an ~8% yield improvement.
. **Orchards (peaches, avocado):** Water savings ranged from 33% to 60%, with stable yields and improved fruit quality.

Overall, the results show that **SB irrigation can deliver "more crop per drop"**, helping farmers save water, maintain productivity, making it a highly effective strategy for sustainable agriculture in water-scarce regions.

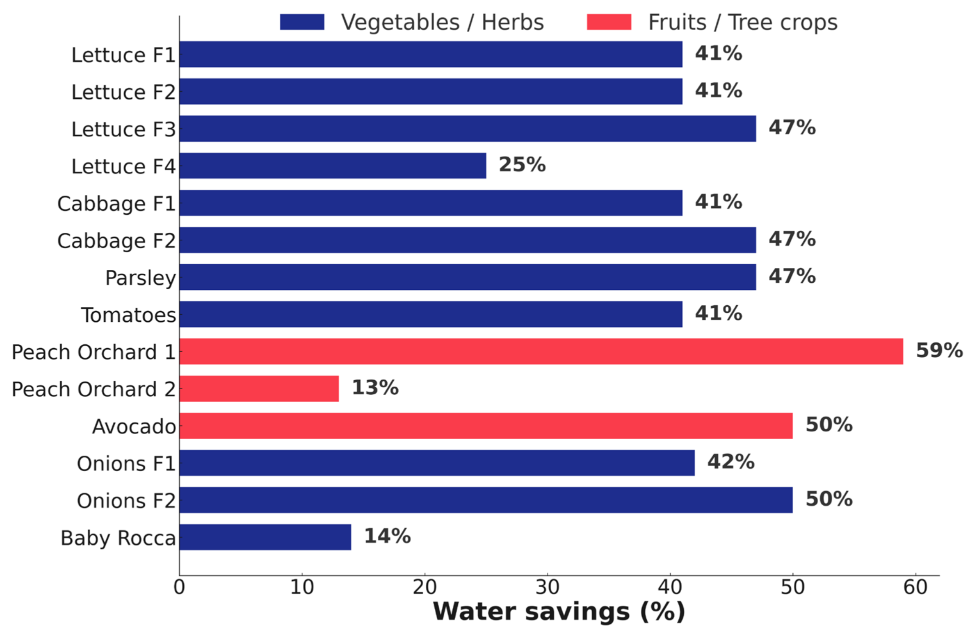


Figure 5: *Per-Farm water savings (SB bs FB) _ Sorted, color-coded by type. Green Horticulture, Brown Perennial crops*

▶ Fertilizer Efficiency

SB fertigation systems led to major improvements in fertilizer efficiency, cutting nutrient use by 50–67% without reducing yields. In several crops, farmers achieved the same productivity with up to 40% less water and 60% less fertilizer, confirming that SB management enables more efficient and sustainable input use.

In greenhouse trials, nitrogen-phosphorus-potassium (NPK) use dropped from 72 kg/ha to 24 kg/ha while in open-field onion production they fell from 58 kg/ha to 19 kg/ha, a 67% reduction in both cases. Despite these reductions, soil analyses confirmed that SB plots maintained balanced nutrient levels, while farmer-based (FB) plots often showed nutrient overloads and retained excess nitrogen. SB guidance enabled targeted adjustments, ensuring balanced phosphorus and potassium uptake in crops such as onions, and avoiding excess nitrogen in leafy vegetables and orchards.

The environmental benefits of sensor-based fertigation are substantial. By applying only what crops required, farmers reduced the risk of nitrate leaching and nitrous oxide emissions, improved nutrient uptake efficiency, and lowered fertilizer costs. SB fertigation followed a “spoon-feeding” approach, providing small, timely doses matched to crop demand.

Although sensors measured soil moisture and bulk electrical conductivity (EC) rather than specific nutrient ions, combined with periodic soil and foliar tests, allowed for accurate calibration of fertilizer needs. Overall, farmers who followed SB recommendations reduced total fertilizer use by an average of 62%, improving soil fertility, lowering costs, and reducing nitrate leaching and nitrous oxide emissions. These results demonstrate that aligning fertigation with crop-specific nutrient targets replaces wasteful, input-heavy practices with a sustainable, profitable, and climate-smart model of crop nutrition.

▶ Soil Health

Soil analysis across the pilot farms showed signs of better balance in fertility and reduced salinity, especially where both moisture and nutrient sensors recommendations were applied. Improvements were most visible in organic matter levels and more stable pH and EC values, indicating healthier soil conditions for crop growth.

To capture overall progress, soil results from each farm were summarized into a single indicator of soil health change. Farms using both sensor types achieved the highest improvements, showing that integrating nutrient and moisture monitoring helps maintain soil stability and supports more sustain able and climate-resilient production practices.

▶ Energy Use and Greenhouse Gas Emissions

Sensor-based systems led to a clear reduction in fuel and electricity consumption across all pilot farms. Because less groundwater was pumped, energy use dropped between **20% and 50%**, depending on the system size and irrigation frequency. This translated directly into lower operating costs and fewer greenhouse gas emissions.

were estimated to decrease by 50–60%. The reduction stemmed mainly from lower diesel use for pumping and more efficient fertilizer application, since both fuel combustion and fertilizer production are key emission sources in agriculture. For example, in two pilot farms, estimated emissions declined from around 730 to 310 kg CO_2e per hectare, meaning only about 40% of previous emissions remained under sensor-based management.

These results show that precision irrigation can help farmers both mitigate emissions and strengthen resilience. In the context of Lebanon’s ongoing energy crisis, reduced fuel dependence enables farms to continue operating despite frequent power shortages and high fuel prices.

2.3 Labour Efficiency

Emissions were estimated using standard activity data. Diesel litres and electricity kWh used for irrigation were multiplied by standard CO_2e emission factors. Fertilizer-related emissions were calculated from the quantities of N, P, and K applied, using accepted averages for manufacturing emissions, plus IPCC default values for minor field emissions from nitrogen. Total emissions per hectare equal the sum of fuel, electricity, and fertilizer emissions. Sensor-based reductions reflect lower pumping and reduced fertilizer use under the same crop cycle.

Sensor-based automation made irrigation and monitoring significantly more efficient, reducing routine workloads and improving overall labour productivity. On average, workers spent 30–50% less time on irrigation tasks, freeing time for other farm management tasks such as crop monitoring and planning field operations. Monitoring time also decreased since irrigation decisions were guided by real-time sensor data rather than field checks.

For example, Open field farmers reduced irrigation hours from around 20 to just 5 hours (−70%), while greenhouse operators reported 30–40% time savings. With the same number of workers, farms were able to manage larger cultivated areas or diversify tasks without increasing total labour hours. Farmers and workers relied on mobile dashboards to monitor conditions instead of daily field visits, improving planning, confidence, and efficiency.

Farmers and workers indicated that automation reduced physical fatigue and made work schedules more predictable. Basic digital skills became increasingly relevant for monitoring applications, marking a shift from repetitive fieldwork to more data-oriented supervision. In some cases, a single worker was able to manage nearly twice the area previously handled.

The pilot also supported decent-work objectives by improving working conditions and technical skills. Automation reduced direct contact with chemical fertilizers and minimized exposure to heat during manual irrigation. Training sessions enhanced farmers' ability to interpret data and apply safe, efficient practices, skills that can support future employment in Lebanon's emerging agritech sector. Overall, farms achieved more efficient irrigation, lower routine workloads, and equal or higher labour productivity, indicating that technology adoption improved both productivity and the quality of work.

2.4 Cost-Effectiveness and Sustainability

SB irrigation and fertigation improved both economic performance and environmental sustainability across trial farms. Automation and data-driven management reduced fertilizer, water, and fuel costs by 30–50% — equivalent to USD 170–412 per hectare per cycle, depending on crop and scale. With equipment costs of about USD 600 per hectare, most farmers recovered their investment within one to three crop cycles. Return on investment (ROI) ranged from 38 % to 328 %, and net profit gains from 8 % to 25 %, driven by lower input costs, stable or higher yields, and improved produce quality. Larger farms also projected positive returns within three years, with faster payback as adoption expands. Reduced dependence on volatile fertilizer and fuel prices, along with better produce quality, further strengthened income stability.

Environmentally, SB management reduced water use by up to 40 %, fertilizer application by over 50 %, and energy consumption by 20–50 %, cutting greenhouse gas (GHG) emissions by an estimated 50–60 % per hectare. Optimized irrigation also minimized groundwater depletion and salinity risks, while reduced fertilizer use decreased nitrate leaching and pollution. These results confirm that economic and environmental gains can be achieved simultaneously through precision irrigation.

Socially, the technology strengthened farmers' technical and digital skills, improved decision-making capacity, and made agricultural work more appealing to younger and more skilled workers. Scaling up adoption could therefore help transform farming in Lebanon by improving food security, conserving natural resources, and enhancing rural livelihoods.

3. Farmer Success Stories and Adoption

To complement the quantitative evidence, this section presents farmer success stories that illustrate the tangible benefits and challenges of adopting sensor-based irrigation and fertigation systems. Spanning orchards and greenhouses in Akkar and the Bekaa Valley, these narratives highlight improvements in productivity, efficiency, and resilience, while also shedding light on the social and economic factors shaping adoption. Together, they demonstrate how smart farming can transform diverse agricultural systems in Lebanon.

Pedro Hilal – Akkar

Pedro Hilal adopted sensor-based irrigation in his lettuce, cabbage, and parsley greenhouses to stabilize yields and quality. The sensor-based system delivered substantial gains across all crops. The system cut water use by 47%, energy by 48%, and fertilizer by 67%, reducing greenhouse gas emissions by 51%. Lettuce matured five days earlier, cabbage six, and parsley two days earlier compared to farmer-managed plots. Yields rose by 23% for lettuce, 15% for cabbage, and 17% for parsley, and all sensor-managed crops were graded as Class A versus 80% in farmer-managed spans. Pedro noted that the system stabilized plant growth, making crops more resilient to climatic fluctuations. Beyond productivity, profitability improved significantly. Revenues per cycle increased by 18%, driven by lower input costs and higher prices for premium-quality produce. Overall profit rose by nearly $2,000 per hectare. With a return on investment of 328% and payback achieved in less than one cycle, Pedro plans to expand the system to his tomato crops next season.

(© ILO, 2025)

(© ILO, 2025)

Workers in farms and produce under vsensor-based (SB) management.

Jarrouj Family – Akkar

The Jarrouj family manages six tunnel greenhouses and markets their produce directly through a small shop. With no prior experience in smart farming, they introduced sensor-based irrigation and fertigation to improve efficiency. Water use fell by 41% (466→273 m³/ha), fertilizer by 65% (68→24 kg/ha), and fuel by 48% (114→59 L), cutting operational costs by 52% ($358→$172). Despite lower inputs, yields rose by 8% and crop quality improved, eliminating lettuce tip burn and bolting. Observed improvements extended to environmental performance, with reduced nitrate odor in runoff water indicating minimized nutrient loss.

The system achieved a 38% return on investment within the first season, with payback expected in under three cycles. The technology also improved labour efficiency, reducing repetitive irrigation tasks, as the family shifted time from irrigation to crop care and marketing, strengthening their minimarket business. The case shows that precision farming delivers strong environmental and financial results even for small family farms.

Tarek Daoud & Riwa Mayta (PLant it) – Tourbol

Agronomists Tarek Daoud and Riwa Mayta manage over 150 greenhouses in Tourbol. Trials on baby Rocca showed 14% savings in both water (192 vs 224 m³/ha) and energy (30 vs 35 L/ha) while maintaining stable yields and quality. Financially, the system cut $26.70 per cycle for every two greenhouses. With 6–7 cycles yearly, they expect full payback within 3–4 years. Their results attracted other farmers to visit and learn from their experience, showing how technology can scale efficiency, reduce costs, and promote sustainable production.

Tarek and Riwa represent a new generation of agronomists driving change through peer learning and practical demonstration. Well-connected across the Bekaa farming community, they host neighboring farmers who visit their greenhouses to observe the sensor systems in action and exchange insights on irrigation and crop management.

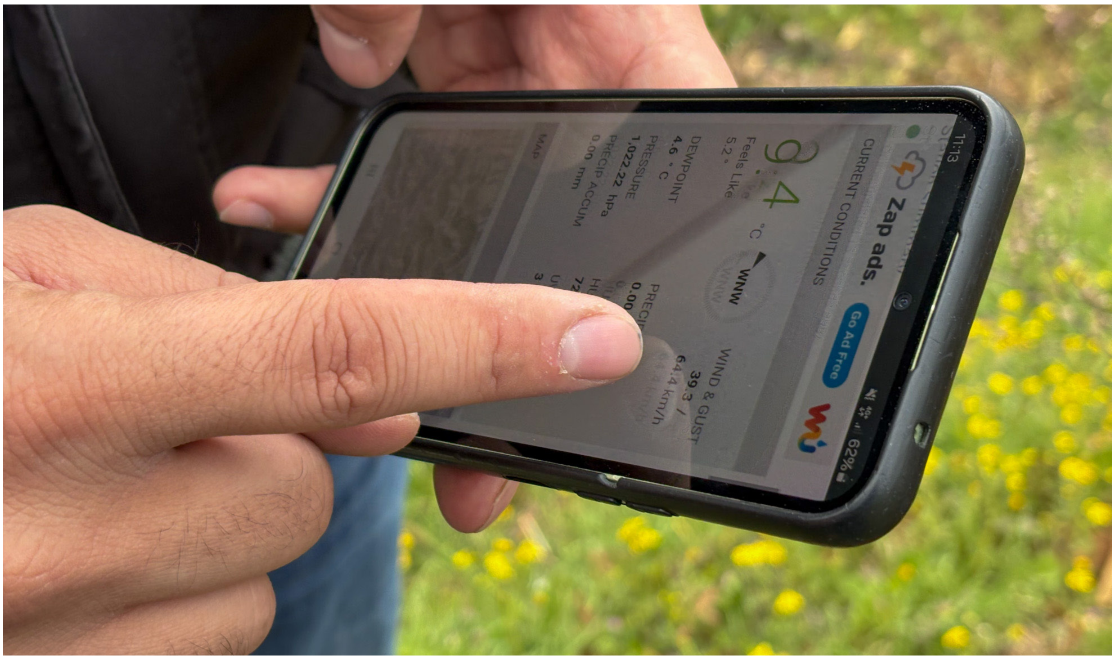
(© ILO, 2025)

Peer-to-peer farmer learning. Tarek Daoud hosts neighboring farmers visiting his greenhouse to observe the sensor-based system and discuss improved irrigation and crop management practices.

Ahmad Attiyeh – West Bekaa

A peach grower managing 1.2 ha of orchards, had a reputation for experimenting with high fertilizer doses "to be safe." Soil tests confirmed that nutrient levels were already far above recommended thresholds. Mid-season, he cut fertilizer use by half in his sensor-based plots after seeing strong growth without extra feeding. Yields were identical in both farmer-managed (FB) and SB plots (~32 tons, ~30–35 kg/tree), while water use also declined by ~13%.

Sensors helped him with time irrigation better and rely on data rather than intuition. His story illustrates that meaningful change in climate-smart agriculture often begins with breaking entrenched habits, and that embracing precision farming can transform wasteful practices into efficient, evidence-based management.



(© ILO, 2025)

Real-time monitoring via mobile application. Sensor data transmitted from the field is accessible through the mobile platform.

Georges Fares –Akkar Cooperative President

As president of the local agricultural cooperative, Georges Fares trialed sensor-based (SB) irrigation and fertigation on his 800 avocado trees. Despite a late frost that devastated fruit set, he considers the season a success.

SB-managed terraces recovered more vigorously after the frost, producing stronger shoots and foliage than farmer-managed (FB) trees. Balanced irrigation and fertigation enhanced resilience, preventing waterlogging or nutrient stress. Georges halved his water and fertilizer use, cutting diesel costs by nearly 40% without compromising tree health. In a normal season, he estimates that these combined savings and quality improvements would yield an ROI of over 200%. Beyond his own farm, Georges became a vocal advocate, sharing results with cooperative members and encouraging wider adoption. Georges' case demonstrates how climate-smart agriculture can build resilience, save resources, and inspire collective change, even under adverse conditions.

(© ILO, 2025)

Digital farm management practice. Georges Fares, President of the Akkar Cooperative, monitors his field's performance and sensor readings through the application.

Eddy & Georges Bou Mouncef (Peach) – West Bekaa

Eddy and Georges Bou Mouncef manage 0.8 ha of terraced peaches, long recognized for their productivity. By integrating sensor-guided irrigation, the brothers achieved modest yield gains (25–30 kg/tree vs. 15–30 kg/tree under traditional management) alongside substantial quality improvements: 90% of fruit in sensor-based plots graded as Class A, compared to 80% under farmer-based management. Fruits were larger, sweeter, and less prone to cracking, reflecting optimal water management and reduced stress during critical fruit-swelling periods. Resource use became more efficient: diesel and pumping requirements decreased by approximately 40%, and fertilizer application was optimized, maintaining yields with half the previous input. Eddy and Georges plan to expand sensor coverage across their entire farm to replicate these gains.

(© ILO, 2025)

Eddy and Georges Bou Mouncef, peach growers, in their orchards demonstrating sensor-guided irrigation.

Elie Jabbour – Qobayat

Elie Jabbour introduced sensor-based irrigation and fertigation in his onion greenhouses to tackle rising input costs. The results were remarkable: water use fell by 42%, fertilizer by 67%, energy by 42%, and greenhouse gas emissions dropped by 56%, while yields increased by 8%, from 30 to 32.4 tons/ha. Financially, Elie's net profit rose by approximately $410/ha, delivering a 68% ROI within a single season.

The improved efficiency allowed workers to focus on higher-value tasks and enabled Elie to launch a small onion nursery, diversifying income, and creating additional employment opportunities.

(© ILO, 2025)

Reviewing technical and scientific data from SmartLand Agri systems.

▶ 4. Key Lessons from the pilot

4.1. Improving efficiency

The pilot confirmed that sensor-based irrigation and fertigation deliver clear agronomic, economic, and environmental benefits for Lebanese agriculture. Across varied crops and production systems, these technologies maintained or increased yields, improved product quality, and reduced input use, demonstrating that farmers can produce more with fewer resources. In a context of water scarcity, high input costs, and climate variability, precision irrigation offers a realistic pathway toward climate-smart, resource-efficient, and profitable farming.

Results showed consistent performance across scales. Both greenhouses and orchards achieved substantial savings in water, fertilizer, and fuel use, coupled with higher quality and faster returns on investment. Greenhouse farmers recorded faster maturation and higher yields, while orchards improved fruit quality and resilience to stress.

Adoption, however, depends on cost, skills, and infrastructure. Early adopters acted as local examples, enabling peer learning and building confidence in the technology. Challenges such as financing, training, and technical integration can be mitigated through cooperative support and tailored capacity-building.

The pilot demonstrates the transformative potential of digital agriculture in Lebanon: enhancing efficiency, strengthening resilience, and modernizing farm management. Such interventions increase the likelihood of widespread adoption, as farmers are more likely to invest in innovations that deliver clear economic returns alongside social and environmental benefits. Scaling up will require combining technology deployment with accessible financing, cooperative dissemination, and inclusive training to ensure that precision agriculture becomes both viable and widespread.

4.2. Implementation Challenges and Enabling Factors

The pilot revealed barriers and opportunities for sensor-based agriculture. Seasonal conditions (snow, mud, limited access), power outages, and poor internet connectivity challenged real-time data use. Technical integration sometimes required adjustments, and interpreting nutrient data was difficult, as sensors measured Electric Conductivity rather than specific nutrient levels. Of the 15 farms, twelve used only moisture sensors improved irrigation scheduling with more variable results. Five of these adopted both sensor types and achieved the highest improvements in fertility and soil structure.

Farmers addressed these challenges through practical solutions such as repositioning equipment, using Wi-Fi hotspots, and scheduling irrigation during peak power hours. Demonstration plots, cooperative support, and peer learning built technical confidence and trust.

Adoption depended on farmers' experience, education, and gender. Younger and more educated farmers adapted faster, while older ones benefited from simplified tools and tailored guidance. Women farmers engaged effectively when given opportunities, showing that inclusive outreach accelerates uptake. Demonstration plots are important for building trust, while cooperative engagement can accelerate dissemination of knowledge, improve accessibility to technology, and support financing mechanisms. Farmers selected for the trials were well-respected within their communities. Participants were encouraged to share trial results within their cooperatives and local networks.

High upfront costs (about $600 per unit) remained the main barrier, especially for smallholders. Flexible financing, cooperative-based models, and subsidies were identified as essential for scaling.

Overall, success relied on four enablers: training, financing, cooperative engagement, and demonstration plots. These created trust, improved access, and supported practical learning. The pilot showed that sensor-based systems can shift agriculture from experience-based practices to data-informed management, improving efficiency and resilience. Scaling adoption requires addressing affordability, accessibility, and inclusion while strengthening cooperative networks and extension services.

Conclusion

The pilot confirmed that sensor-based irrigation and fertigation deliver clear agronomic, economic, and environmental benefits for Lebanese agriculture. Across varied crops and production systems, these technologies maintained or increased yields, improved product quality, and reduced input use, demonstrating that farmers can produce more with fewer resources. In a context of water scarcity, high input costs, and climate variability, precision irrigation offers a realistic pathway toward climate-smart, resource-efficient, and profitable farming.

Results showed consistent performance across scales. Both greenhouses and orchards achieved substantial savings in water, fertilizer, and fuel use, coupled with higher quality and faster returns on investment. Greenhouse farmers recorded faster maturation and higher yields, while orchards improved fruit quality and resilience to stress.

Adoption, however, depends on cost, skills, and infrastructure. Early adopters acted as local examples, enabling peer learning and building confidence in the technology. Challenges such as financing, training, and technical integration can be mitigated through cooperative support and tailored capacity-building.

The pilot demonstrates the transformative potential of digital agriculture in Lebanon: enhancing efficiency, strengthening resilience, and modernizing farm management. Such interventions increase the likelihood of widespread adoption, as farmers are more likely to invest in innovations that deliver clear economic returns alongside social and environmental benefits. Scaling up will require combining technology deployment with accessible financing, cooperative dissemination, and inclusive training to ensure that precision agriculture becomes both viable and widespread.

Funded by

Sweden
Sverige

ilo.org

International Labour Organization
Regional Office for the Arab States
Aresco Centre - Justinien Street - Kantari
Beirut - Lebanon