

USING DISTRIBUTION UNIFORMITY TO EVALUATE IRRIGATION PERFORMANCE UNDER FARMER-MANAGED CONDITIONS IN THE JORDAN VALLEY

UTILISATION DE L'UNIFORMITÉ DE DISTRIBUTION POUR ÉVALUER LES PERFORMANCES DE L'IRRIGATION EN CONDITIONS DE GESTION PAR LES AGRICULTEURS DANS LA VALLÉE DU JOURDAIN

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ABSTRACT

Jordan is among the most water-scarce countries in the world, with annual renewable freshwater availability of approximately 61 m³ per capita, far below the absolute water scarcity threshold of 500 m³ per capita (MWI, 2023). Agriculture is the dominant water-consuming sector, making improvement of farm-level irrigation performance essential for water productivity and agricultural livelihoods. This study evaluated irrigation performance on 100 randomly selected farms across the Northern, Middle, and Southern Jordan Valley, covering citrus, greenhouse vegetables, open-field vegetables, and date palms under micro-irrigation systems. Emission uniformity (EU) was assessed through direct field measurements of emitter discharge and classified using the Merriam and Keller (1978) criteria. Irrigation supply adequacy was evaluated using Relative Water Supply (RWS) and Relative Irrigation Supply (RIS), with crop water requirements estimated using CROPWAT procedures based on FAO-56 methods (Allen et al., 1998).

EU values generally ranged from acceptable to excellent, indicating that the hydraulic condition of most micro-irrigation systems was technically adequate. However, farms applying similar seasonal water volumes did not necessarily achieve similar irrigation performance, as differences in emitter clogging, pressure variation, filter cleaning, line flushing, and leak repair affected water distribution uniformity. In several cases, technically adequate systems were still associated with over-irrigation or under-irrigation because scheduling was based on farmer experience and visual assessment rather than calculated crop water requirements. The findings demonstrate that micro-irrigation infrastructure alone is not sufficient to ensure efficient water use. Emission uniformity must be interpreted together with applied irrigation volume, crop water demand, maintenance practices, and scheduling behavior. The study highlights the need for practical irrigation scheduling tools, routine system maintenance, farmer record-keeping, and regular field-based uniformity assessment.

Keywords: emission uniformity; irrigation scheduling; maintenance practices; micro-irrigation; Jordan Valley; water productivity; relative water supply.

RÉSUMÉ

La Jordanie compte parmi les pays les plus pauvres en eau au monde, avec une disponibilité annuelle en eau douce renouvelable d'environ 61 m³ par habitant, très inférieure au seuil de pénurie d'eau absolue de 500 m³ par habitant (MWI, 2023). L'agriculture est le principal secteur consommateur d'eau, ce qui rend indispensable l'amélioration des performances de l'irrigation à l'échelle de l'exploitation pour accroître la productivité de l'eau et préserver les moyens de subsistance agricoles. Cette étude a évalué les performances de l'irrigation dans 100 exploitations sélectionnées

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aléatoirement dans les parties nord, centrale et sud de la vallée du Jourdain, couvrant les agrumes, les légumes sous serre, les légumes de plein champ et les palmiers dattiers cultivés sous micro-irrigation. L'uniformité d'émission (EU) a été évaluée par des mesures directes du débit des émetteurs sur le terrain et classée selon les critères de Merriam et Keller (1978). L'adéquation de l'approvisionnement en eau d'irrigation a été évaluée au moyen de l'approvisionnement relatif en eau (RWS) et de l'approvisionnement relatif en eau d'irrigation (RIS), les besoins en eau des cultures étant estimés selon les procédures CROPWAT fondées sur les méthodes FAO-56 (Allen et al., 1998). Les valeurs d'EU se situaient généralement entre des niveaux acceptables et excellents, ce qui indique que l'état hydraulique de la plupart des systèmes de micro-irrigation était techniquement adéquat. Toutefois, des exploitations appliquant des volumes d'eau saisonniers similaires n'obtenaient pas nécessairement des performances d'irrigation comparables, car l'obstruction des émetteurs, les variations de pression, le nettoyage des filtres, le rinçage des conduites et la réparation des fuites influaient sur l'uniformité de distribution de l'eau. Dans plusieurs cas, des systèmes techniquement adéquats restaient associés à une surirrigation ou à une sous-irrigation, la programmation reposant sur l'expérience des agriculteurs et l'évaluation visuelle plutôt que sur les besoins calculés en eau des cultures. Les résultats montrent que l'infrastructure de micro-irrigation ne suffit pas, à elle seule, à garantir une utilisation efficace de l'eau. L'uniformité d'émission doit être interprétée conjointement avec le volume d'irrigation appliqué, les besoins en eau des cultures, les pratiques d'entretien et les modalités de programmation. L'étude souligne la nécessité d'outils pratiques de programmation de l'irrigation, d'un entretien régulier des systèmes, de la tenue de registres par les agriculteurs et d'évaluations régulières de l'uniformité sur le terrain.

Mots-clés : Uniformité des émissions; programmation de l'irrigation; Pratiques d'entretien; Micro-irrigation; Vallée du Jourdain; Productivité de l'eau; Approvisionnement relatif en eau.

INTRODUCTION

Jordan is among the most water-scarce countries in the world. Annual renewable freshwater resources are estimated at around 61 m³ per capita, far below the internationally recognised absolute water scarcity threshold of 500 m³ per capita (MWI, 2023; World Bank, 2023). This acute scarcity is driven by naturally limited water resources, population growth, refugee influxes, over-abstraction of groundwater, and climate change impacts. In 2023, total available water from all sources amounted to 1,127 million m³, of which groundwater, surface water, and treated wastewater represented the main sources of supply (MWI, 2024). With increasing population and climate pressure, Jordan's per-capita renewable freshwater availability is expected to decline further in the coming decades (Foresight4Food, 2024).

Agriculture is the dominant water-consuming sector in Jordan, accounting for more than half of total annual freshwater use while contributing a smaller share to national GDP (MWI, 2024; World Bank, 2023). Improving irrigation performance is therefore a strategic priority for water security, food production, and rural livelihoods. The Jordan Valley is particularly important because it is the country's most productive irrigated agricultural region. It combines favourable winter production conditions, high-value crops, and extensive use of pressurised irrigation systems.

The Jordan Valley extends along the western border of Jordan from the northern valley to the Dead Sea area. Rainfall decreases from the Northern Jordan Valley to the Southern Jordan Valley, creating distinct agro-climatic conditions and cropping patterns (Salahat and Al-Qinna, 2015). The Northern Jordan Valley is characterised mainly by citrus production, the Middle Jordan Valley by greenhouse vegetables and date palms, and the Southern Jordan Valley by open-field vegetables. Water sources also differ, including surface water, groundwater, spring water, treated wastewater, and blended water. These differences create a useful field setting for assessing irrigation performance under varied farmer-managed conditions.

Over recent decades, the adoption of pressurised micro-irrigation systems, including drip emitters and micro-sprinklers, has been widely promoted as a way to improve water use efficiency. However, the installation of a micro-irrigation system does not by itself guarantee efficient water management. The actual performance of such systems depends on emitter condition, pressure distribution, filtration, flushing, leak repair, and the timing and duration of irrigation events. A system may be technically capable of applying water efficiently, yet still be poorly managed if irrigation is not scheduled according to crop water needs or if maintenance is insufficient.

Merriam and Keller (1978) established practical approaches for evaluating farm irrigation systems, including emission uniformity. Mizyed and Kruse (1989) identified manufacturing variation, pressure fluctuation, and emitter clogging as important determinants of trickle irrigation uniformity. At the level of irrigation adequacy, Relative Water Supply (RWS) and Relative Irrigation Supply (RIS) are commonly used to compare water applied with crop water requirements (Malano and Burton, 2001; Parra et al., 2020). These indicators help identify whether water application exceeds or falls below crop demand, but do not show whether the applied water is distributed uniformly within the field. A complete diagnosis of irrigation performance therefore, requires both quantity-based and distribution-based indicators.

This study addresses this gap by integrating field-based emission uniformity measurements, farmer-recorded irrigation applications, maintenance practices, and irrigation scheduling behavior across 100 farms in the three zones of the Jordan Valley. The specific objectives are: (1) to assess emission uniformity of micro-irrigation systems under current farmer-managed field conditions; (2) to estimate irrigation supply adequacy using farmer records and field-reported irrigation practices in relation to calculated crop water requirements; (3) to examine how maintenance practices affect distribution uniformity; (4) to document farmer irrigation scheduling behavior; and (5) to identify practical interventions to improve farm-level irrigation performance and water productivity.

METHODOLOGY

Study Area and Farm Selection

The study was conducted in the Northern, Middle, and Southern Jordan Valley. These zones differ in climate, cropping patterns, water sources, and irrigation system types. The Northern Jordan Valley is dominated by citrus orchards, commonly irrigated using viro-jet micro-sprinklers. The Middle Jordan Valley includes greenhouse vegetables and date palms, using both inline drip emitters and micro-sprinklers. The Southern Jordan Valley is dominated by open-field vegetables irrigated mainly with inline drip emitters.

One hundred farms were randomly selected for evaluation and stratified by zone to reflect the major crops and irrigation system types found across the Valley. The sample included 40 farms in the Northern Jordan Valley, 35 farms in the Middle Jordan Valley, and 25 farms in the Southern Jordan Valley. The selected farms represented citrus, greenhouse vegetables, date palms, and open-field vegetables under farmer-managed micro-irrigation systems.

Table 1. Farms selected for evaluation by zone

Zone	No. of farms	Major crop(s)	Main irrigation system
Northern Jordan Valley	40	Citrus	Viro-jet micro-sprinklers and drip emitters
Middle Jordan Valley	35	Greenhouse vegetables and date palms	Inline drip emitters and viro-jets
Southern Jordan Valley	25	Open-field vegetables	Inline drip emitters

Emission Uniformity Assessment

Emission uniformity (EU) was selected as the main hydraulic performance indicator because it provides a standard and comparable measure of how evenly water is delivered through emitters across an irrigation subunit. EU was calculated from direct field measurements of emitter discharge rates following Merriam and Keller (1978), as commonly applied in trickle and micro-irrigation system evaluation.

$$EU (\%) = (q_n / q_{ave}) \times 100$$

where EU is emission uniformity (%), q_n is the mean discharge rate of the lowest one-quarter of all field emitter measurements (L/h), and q_{ave} is the mean discharge rate of all emitters measured (L/h). For each farm, discharge measurements were taken at systematically distributed locations across the irrigation subunit to capture spatial variability in pressure and emitter performance. Systems were classified using the Merriam and Keller (1978) thresholds shown in Table 2.

Table 2. Emission uniformity classification (Merriam and Keller, 1978)

EU (%)	Classification
<70	Poor
70-80	Acceptable
80-90	Good
≥90	Excellent

Irrigation Supply Adequacy and Management Assessment

Two dimensionless indicators, Relative Water Supply (RWS) and Relative Irrigation Supply (RIS), were used to assess the adequacy of irrigation supply in relation to crop water demand, following Malano and Burton (2001) and Parra et al. (2020). RWS compares total available water with crop evapotranspiration, while RIS compares irrigation supply with the net irrigation requirement after accounting for effective precipitation.

$$RWS = (I + Pe) / ETc$$

$$RIS = I / (ETc - Pe)$$

where I is the total seasonal irrigation supply derived from farmer records, Pe is effective precipitation, and ETc is crop evapotranspiration. Values greater than 1.0 indicate over-supply; values below 1.0 indicate under-supply. Irrigation supply was estimated from farmer-recorded irrigation frequency, duration, cultivated area, and observed discharge rather than formal allocation figures, reflecting actual farmer-managed irrigation. ETc was estimated using CROPWAT 8.0 based on FAO-56 procedures (Allen et al., 1998). Soil texture was analyzed using standard hydrometer methods to support the interpretation of soil water-holding capacity and irrigation behavior.

Semi-structured interviews were conducted in Arabic with all 100 farm operators during the farm visits. The interview protocol covered five thematic areas: (1) criteria and cues used to decide when to irrigate; (2) typical duration and frequency of irrigation events by crop growth stage; (3) methods used to assess whether crops had received sufficient water; (4) awareness and use of crop water requirement data, weather information, or soil moisture monitoring tools; and (5) perceptions of water adequacy under current delivery conditions.

Interview responses were recorded and summarised by theme. Responses were cross-referenced with observed field conditions, EU measurements, and farmer-recorded irrigation practices to identify relationships between management behaviour, applied irrigation volumes, and system performance.

RESULTS

Irrigation Supply Adequacy

Table 2 presents annual ET_c, farmer-recorded irrigation supply, and the resulting RWS and RIS values for the major crops in each zone. The results indicate clear differences in the adequacy of farmer-applied irrigation between crops and locations. Some cropping systems received water volumes above estimated crop water requirements, while others received less than estimated requirements.

Citrus in the Northern Jordan Valley showed slight over-supply, with RWS and RIS values above 1.0. Greenhouse vegetables in the Middle Jordan Valley also showed moderate over-supply. By contrast, date palms in the Middle Jordan Valley and open-field vegetables in the Southern Jordan Valley showed under-supply relative to calculated crop water requirements. These results suggest that actual irrigation volumes applied by farmers were not consistently aligned with crop water requirements, highlighting the importance of farm-level scheduling and irrigation planning.

Table 2. Annual ET_c, farmer-recorded irrigation supply, RWS and RIS by crop and zone

Crop	Zone	Annual ET _c (L/m ²)	Irrigation supply (L/m ²)	RWS	RIS	Interpretation
Citrus	Northern JV	888.3	705.0	1.09	1.12	Slight over-supply
Greenhouse vegetables	Middle JV	313.2	368.0	1.17	1.17	Moderate over- supply
Date palms	Middle JV	1,260.1	380.0	0.51	0.37	Severe under-supply
Open-field vegetables	Southern JV	~620.0	365.5	~0.59	~0.66	Under-supply

Emission Uniformity

Of the 100 farms evaluated, 48% used viro-jet micro-sprinklers and 52% used inline drip emitters. In the Northern Jordan Valley, most citrus farms were served by viro-jets, with the remaining farms using drip emitters. In the Middle and Southern Jordan Valley, inline drip emitters were the dominant system, particularly for greenhouse vegetables and open-field vegetables.

EU results for all farms fell within the acceptable to excellent classification range. For viro-jets, EU ranged from 76.35% to 96% with a mean of approximately 88%. For inline drip emitters, EU ranged from 71.9% to 96% with a mean of approximately 86%. No farm was classified as poor (EU < 70%). The majority of systems of both types recorded EU values in the good to excellent range, with no statistically significant difference in mean EU between viro-jets and drip emitters.

These findings indicate that the hydraulic performance of most micro-irrigation systems was technically adequate. However, adequate EU does not necessarily mean that irrigation management was efficient. EU measures how evenly water is distributed within the field, but it does not show whether the amount applied was appropriate for crop water demand or whether irrigation was scheduled at the correct time.

Maintenance Practices and Scheduling Behavior

Farms reporting regular maintenance generally recorded higher and more stable EU values. Farms where maintenance was conducted only after visible problems appeared showed lower EU values and greater inter-emitter variation. This is important because several farms applied similar seasonal irrigation volumes but recorded different uniformity levels, demonstrating that total applied water at farm level does not reliably reflect water effectively received by crops across the field. Where

maintenance was weak, partial clogging, pressure imbalance, or leakage redistributed water unevenly, leaving some areas under-irrigated while others received excess.

Interviews with all 100 farm operators revealed a near-universal pattern: irrigation decisions were based on visual observation, farmer experience, and water delivery availability. No farm operator reported using soil moisture sensors, tensiometers, evapotranspiration-based scheduling tools, or weather-based irrigation advice. Primary triggers for irrigation were visible plant stress, dry soil surface near the root zone, and notification of an available delivery slot. In all three zones, irrigation duration was governed by simple proxies such as basin filling, soil surface appearance, or elapsed time. This introduced variability in both the amount and timing of irrigation, even where EU values were acceptable.

DISCUSSION

The RWS and RIS results confirm that farmer-recorded irrigation applications were not consistently aligned with calculated crop water requirements. Some crops received water in excess of estimated demand, while others received less. This confirms that irrigation performance cannot be inferred from the presence of micro-irrigation infrastructure alone, nor from total applied volume alone. Even technically adequate systems may deliver water inefficiently if scheduling is not linked to crop growth stage, soil water conditions, and estimated evapotranspiration. The use of farmer records rather than formal allocation figures is methodologically important here: it captures actual irrigation behavior under field conditions, making RWS and RIS genuine indicators of farm-level management rather than planned supply.

The EU results, with all farms falling within the acceptable to excellent range, confirm that micro-irrigation infrastructure in the study area was generally functioning within acceptable hydraulic parameters. The comparable EU ranges for viro-jets and inline drip emitters are noteworthy. Despite their different operating characteristics, both system types achieved similar uniformity under observed conditions. However, this should not be interpreted as a reason to reduce attention to maintenance. Micro-irrigation systems are vulnerable to progressive performance decline through emitter clogging, sediment accumulation, biological growth, chemical precipitation, and pressure variation (Nakayama and Bucks, 1991; Adin and Sacks, 1991; Yu and Li, 2018). Regular EU testing can identify whether poor crop response or uneven wetting is caused by distribution problems rather than by insufficient total water volume—a distinction that farmers managing by visual cues alone cannot reliably make.

A central finding of this study is that similar farmer-recorded irrigation applications can result in different irrigation outcomes. Emission uniformity captures the distribution dimension of performance. A farm with high EU distributes water more evenly across the field, while a farm with lower EU may leave some areas under-irrigated and others over-irrigated, even when total seasonal water application is similar. This distinction is especially relevant in micro-irrigation systems, where emitter clogging, pressure differences, and leakage reduce distribution uniformity without necessarily appearing in aggregate volume records. An integrated diagnostic framework is therefore required: RWS and RIS indicate whether applied volume is adequate relative to crop demand; EU indicates whether that volume is distributed uniformly; maintenance practices explain EU differences across farms using similar systems; and scheduling behavior explains why applied water may exceed or fall below crop requirements.

The near-universal reliance on visual cues with no reported use of soil moisture sensors, evapotranspiration tools, or weather-based advisory systems represents a significant barrier to improving water use efficiency. This is consistent with documented patterns in farmer irrigation behavior in supply-driven distribution systems (Shatnawi et al., 2005; Malano and Burton, 2001). Improved scheduling does not necessarily require advanced technology. Simple crop-stage irrigation calendars, duration tables, and farmer logbooks can help match irrigation timing and volume to crop water demand. Extension services should therefore move beyond promoting micro-irrigation technology as a stand-alone solution. Training should address the full irrigation management cycle:

estimating crop water needs, scheduling events, maintaining system condition, and keeping records. For water-scarce regions such as the Jordan Valley, water productivity depends on management as much as technology.

CONCLUSION

This study evaluated irrigation performance across 100 farms in the Northern, Middle, and Southern Jordan Valley by integrating field-based emission uniformity measurements, farmer-recorded irrigation applications, crop water requirement estimates, maintenance practices, and irrigation scheduling behaviour. The findings provide a practical diagnosis of micro-irrigation performance under farmer-managed conditions in one of the world's most water-scarce agricultural regions.

The results show that most micro-irrigation systems were hydraulically functional, with EU values generally falling within acceptable to excellent ranges. However, this did not automatically translate into efficient water management. Farmer-recorded irrigation applications were not consistently aligned with calculated crop water requirements, and farms with similar applied water volumes showed different levels of distribution uniformity. This confirms that irrigation efficiency cannot be inferred from the presence of drip or micro-sprinkler systems alone, nor from total applied water alone.

The study demonstrates that irrigation performance depends on the interaction between four factors: system condition, maintenance practices, irrigation scheduling, and crop water demand. Regular maintenance, including filter cleaning, lateral flushing, emitter inspection, and timely repair of leaks, is essential to preserve uniform water distribution. At the same time, scheduling decisions must be linked more closely to crop growth stage, soil water conditions, and estimated evapotranspiration. Without these management practices, micro-irrigation systems may still result in over-irrigation, under-irrigation, or uneven water distribution.

The findings highlight three priority areas for improving farm-level water productivity in the Jordan Valley. First, practical irrigation scheduling tools should be developed and promoted, using simple crop-stage guidance that farmers can apply under real field conditions. Second, routine maintenance protocols should be strengthened through farmer training, WUA support, and periodic field checks of emission uniformity. Third, farmer record-keeping should be improved so that irrigation frequency, duration, and applied volumes can be monitored and adjusted over time.

Overall, the study confirms that micro-irrigation technology is a necessary but insufficient condition for efficient water use. Improving irrigation performance requires moving beyond hardware adoption toward integrated irrigation management, combining technical system evaluation with farmer behaviour, maintenance routines, and scheduling practices.

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