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Improvement of Current Performance in Collective Water Delivery Systems of Calabria (Southern Italy)

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The performance of three water delivery systems in Calabria (Southern Italy) was evaluated throughout four irrigation seasons, using indicators of adequacy, efficiency, dependability and equity. Subsequently, three scenarios for improving irrigation management (replacement of sprinkler methods with micro-irrigation, an arranged-demand water delivery system together with an irrigation advisory service, and a combination of both actions) were simulated. In the current situation the water delivered to farms is not adequate for irrigation requirements, but it is used without significant waste; the water delivery service is not uniform in time and space. In this case of poor adequacy and dependability of water delivery systems, the introduction of arranged demand distribution and irrigation advisory service is more efficacious than the replacement of current sprinkler systems with micro-irrigation. The adoption of the combined scenario is advisable to assure the optimal performance of water delivery systems and to make the collective service more adequate and reliable.

1. Introduction

Often water delivery systems suffer from problems such as capacity lower than peak demand, irregular delivery rates and low irrigation efficiency and uniformity (Nam et al., 2016). This is the case of many of the 11 Water Users Associations of Calabria (Southern Italy), a region where agriculture is by far the most important economic sector. Here, the performance of collective irrigation services is generally poor, due to inadequate water delivery, with low farmer satisfaction (Zema et al., 2015). In these cases, the assessment of irrigation performance represents for WUAs' managers a point of departure for improvements, provided that water-use records are available for individual land parcels. By these data it is possible not only to evaluate the collective irrigation performance on a quantitative basis, but also to simulate alternative management actions, in order to improve the performance of the irrigation systems. This study evaluates over four irrigation seasons adequacy, efficiency, dependability and equity of three water delivery systems in Calabria, using the four performance indicators developed by Molden and Gates (1990). The performances of three alternative management scenarios, including proposals for improving collective irrigation, are simulated and compared.

2. Materials and methods

2.1 Description of the study area

The three investigated water delivery systems ("Angitola 3DMF", irrigated area of 117 ha, "Angitola 6DMF", 86 ha, and "Savuto", 411 ha) fall within the Water Users Association "Tirreno Catanzarese" (Calabria, a region characterized by a semi-arid climate, which makes the irrigation requirement of crops high in summer) (Figure 1). The main crops are olives, citrus and other fruits, vegetables (mainly tomatoes, aubergines and onions), gardens, forage, maize, and are mainly irrigated with sprinkler systems.
The irrigation water is delivered in pressured pipelines, distributed on demand and charged to users on water unit volumes. The three water delivery systems were designed by probabilistic criteria and currently are not able to allocate water simultaneously to the whole area.

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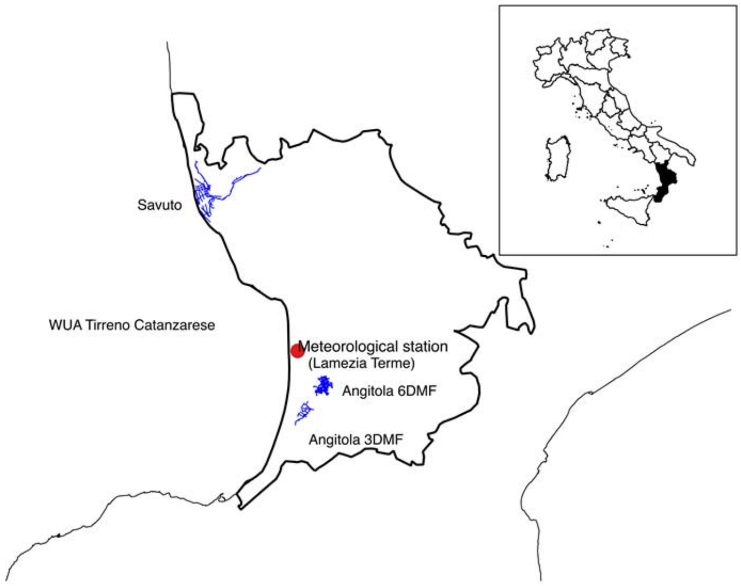

Figure 1 – Location of the studied water delivery systems (Calabria, Southern Italy).

2.2 Estimation of the total/net irrigation requirements and collection of the water delivery data

The net irrigation requirement of each crop (in addition to precipitation) was estimated using the software CROPWAT 8.0 (Clarke et al., 1998; FAO, 2009). The water balance was performed daily for each crop over four irrigation seasons (from April to September). The daily meteorological data required by CROPWAT were measured at a measuring station (Lamezia Terme) inside the WUA (Figure 1). In relation to the crop data, the root depth and crop coefficients for estimating evapo-transpiration (by Penman-Monteith model) were derived from FAO guidelines; the farm cultivation practices (i.e. dates and operations) were identified by interviewing a sample of 30 farmers. Soil hydrological parameters, in the absence of direct measurements, were estimated using the Pedo Transfer Function of Saxton et al. (1986) on the basis of the texture reported by the Soil Map of the Calabria Region (ARSSA, 2003). The soils are mainly sandy loam (65% of sand, 22% of silt and 13% of clay). The total irrigation requirement of each crop (henceforth indicated as "water required") was calculated from the net irrigation requirement considering farm irrigation efficiencies of 0.70 for sprinklers, 0.85 for sprayers and 0.95 for drippers, accordingly to FAO guidelines. Finally, daily data of total irrigation requirement were aggregated at monthly scale. The water volumes delivered to users (henceforth indicated as "water delivered" or "water delivery") were measured by the automated system "Acquacard®" at the farm hydrants. Subsequently, such data were classified per water delivery system, year (irrigation season), month and crop.

2.3 Description of the performance indicators

For the month "j" of each irrigation season and farm outlet "i", the water delivered (WD_{ij}, [m^3 ha^{-1} $month^{-1}$]) and the water required per unit area (WR_{ij}, [m^3 ha^{-1} $month^{-1}$]) were considered. On the basis of the ratios WD_{ij}/WR_{ij} or WR_{ij}/WD_{ij}, the indicators of Molden and Gates (1990) of adequacy (AD), efficiency (EF), dependability (DE) and equity (EQ) were evaluated in each of the three water delivery systems. Beside the study of Molden and Gates (1990), the literature provides ample information about these indicators together with calculation methods and equations and there more details can be found. The indicator of adequacy "AD" assesses to what extent delivered water met irrigation requirements (Molden and Gates, 1990). In particular, if AD < 1, the irrigation requirement is not satisfied by the water delivery system and the irrigation service is "inadequate". The indicator of efficiency "EF" answers the question of whether there is excessive delivery of water in relation to the crop needs. In particular, if EF < 1, there is a surplus of delivered water compared to required volume and thus the delivery service is not "efficient". Dependability indicates the temporal uniformity in the ratio of amounts of water delivered to amounts of water required. The indicator of dependability "DE" measures temporal uniformity (i.e. over the irrigation season) of the relative amount of water delivered to the different farm outlets. A value of DE close to zero indicates an irrigation service uniform in time and, therefore, "dependable" throughout the irrigation season. Equity addresses the extent of fairness of water distribution among users. The indicator of equity "EQ" measures the spatial variability (i.e. among the different farm outlets) of the relative amount of water delivered during the irrigation season. A value of EQ close to zero indicates an irrigation service uniform in space and, therefore, "equitable" among the users. Of course, it is practically impossible to achieve the ideal values for all the indicators considered; thus, in this study the standard values reported by Molden and Gates (1990) were adopted as reference limits: (i) AD good if ≥ 0.90, fair in the range 0.80 – 0.89 and poor if < 0.80; (ii) EF good if ≥ 0.85, fair in the range 0.70 – 0.84 and poor if < 0.70; (iii) DE good if ≤ 0.10, fair in the range 0.11 – 0.20 and poor if > 0.20; (iv) EQ good if ≤ 0.10, fair in the range 0.11 – 0.25 and poor if > 0.25.

2.4 Analysis of the performance indicators

In the current situation (in the following indicated as "scenario 0"), for each farm supplied with irrigation water in the three studied water delivery systems, WD, WR and their ratios were calculated monthly for each irrigated crop (from April to September) throughout each of the four irrigation seasons. After this, the indicators AD, EF, DE and EQ were calculated at an annual scale (grouping the "n" months of each irrigation season) and the related mean values were derived. Subsequently, three possible management scenarios, aiming at improving the unsatisfactory performance of the analysed water delivery systems, were evaluated through the four indicators above mentioned. These simulation activities may be considered by the irrigation managers and users as a preliminary analysis of the feasibility of the planned interventions. In a first scenario ("1"), the adequacy of the water delivery systems was improved by simulating micro-irrigation (by sprayers or drippers) farm systems in replacement of the current sprinkler irrigation for vegetables, citrus and olive groves as well as other orchards. In the second scenario ("2"), to increase system dependability, the following management actions were simulated: (i) a “limited rate arranged-demand” water distribution method (Merriam et al., 2007) (in the following simply indicated as “arranged demand”), in replacement of the current on-demand method; (ii) an irrigation advisory service, based on the water balance of crops, which suggests irrigation requirements to users using internet or SMS. Finally, a third combined scenario ("3") includes both improvement measures mentioned above. The water delivery planned in scenarios "2" and "3" simulates a “semi-demand” water distribution method in which the irrigator requests a specific volume of water and flow rate to be arranged with WUA management. More specifically, under this arranged demand method, the farmer requests a specific water volume and flow rate, following the suggested time and volume for crop irrigation. The WUA managers check if the requests can be satisfied by the operational flow and delivery sequence selected, and the sector assignations. If not, new manager-farmer arrangements will have to be made (Mateos et al., 2002).
All the simulated scenarios kept the same seasonal volumes of delivered water per crop. In scenarios "2" and "3", the irrigation water volumes to be delivered to each farm by the irrigation network were estimated as the product of the water delivered in each irrigation season by a monthly coefficient; this latter was calculated as the ratio between the monthly and the seasonal irrigation requirements estimated by CROPWAT. The effects on the water delivery systems of these scenarios were evaluated by the four performance indicators.

3. Results and discussions

3.1 Analysis of the performance indicators in the current scenario

The analysis of the water delivery performance in "Angitola 3DMF" system highlighted poor adequacy (mean AD = 0.57) and dependability (mean DE = 0.43), but good efficiency (mean EF = 0.92), and equity (mean EQ = 0.09) during the monitored period of four years. Adequacy (0.77) and dependability (0.25) were quite satisfactory only in citrus groves, since the values of these indicators were slightly different from the acceptance limits (0.80 and 0.20 respectively) (Figure 2a). In the system "Angitola 6DMF" mean values of adequacy (0.55), dependability (0.49) and equity (0.33) of the irrigation service over the monitored irrigation periods were far from the acceptance limits (0.80, 0.20 and 0.25 respectively), while the efficiency in water resource exploitation (0.82) was generally fair; dependability was acceptable only for gardens (0.17) (Figure 2b). Over the monitored period the following water delivery performances were detected in the system "Savuto": very poor adequacy (0.44) and dependability (0.62); good efficiency (0.90); fair equity (0.13). The water delivered was adequate (AD = 0.83) and dependable (DE = 0.19), but the irrigation service was inefficient (EF = 0.69) and inequitable (EQ = 0.44) for citrus groves (Figure 2c). Therefore, the analysis carried out for the current situation of the three studied water delivery systems showed systemic problems that are discussed below.
Firstly, the water volume delivered was never sufficient to satisfy the irrigation requirements of crops (as shown by the indicator of adequacy), with few exceptions. In peak irrigation period, the water delivery systems analysed in this study are not able to allocate water simultaneously to all the requiring farms and this

generates problems of inadequate water volumes delivered, because of the insufficient capacity of the hydraulic infrastructure. Moreover, the individual irrigation programs of the farmers do not appear suitable for the management of the water delivery systems. Since the users did not report a reduction in crop yield, it may be deduced that farmers irrigated crops with additional resources, such as groundwater and/or potable water, often without authorization (as sometimes reported by local authorities). However, the fair value of the indicator of efficiency indicated that the available water volume, delivered to the crops in the three water delivery systems, was properly used for irrigation. Secondly, as shown by the poor indicator of dependability, the systems were not able to deliver water at the desired time, and thus the irrigation service was not uniform over time. This may be attributable to a farmers' lack of knowledge about times of supplying irrigation water to crops: in other words, often crops were irrigated when not necessary or, conversely, in some periods the irrigation requirement remained unsatisfied, regardless of a scheduled hydrological balance. Finally, few cases (i.e. irrigation of four gardens and four orchards in the water delivery system "Angitola 6DMF" and four citrus groves in "Savuto") of very low spatial uniformity in water delivery to the irrigated farms were recorded, since the indicator of equity was on average lower than 0.25. However, equity of water delivery is a difficult objective to achieve because it is influenced by several factors and, among these, mainly by infrastructure inadequacy: this is the reason why the problem of equity improvement was not analysed in depth in those situations in which a low spatial uniformity of water delivery was recorded.

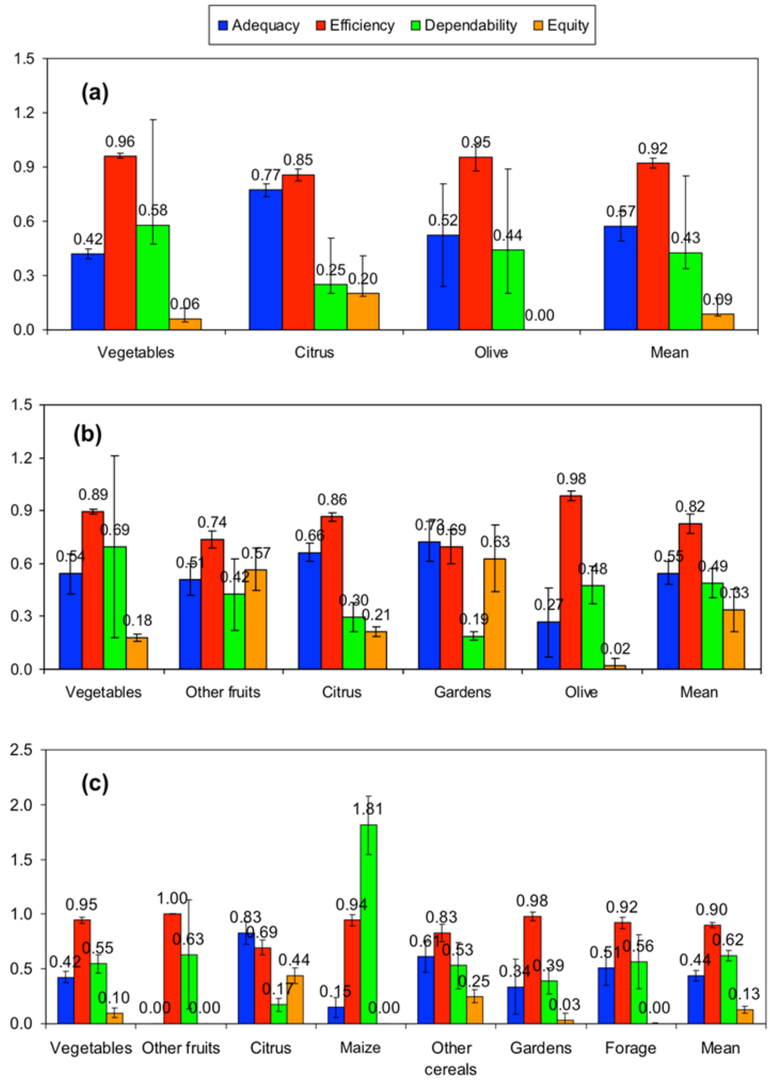

Figure 2 – Current indicators (means and std. devs.) of adequacy ("AD"), efficiency ("EF"), dependability ("DE") and equity ("EQ") in the water delivery systems "Angitola 3DMF" (a), "Angitola 6DMF" (b) and "Savuto" (c).

3.2 Analysis of the performance indicators under improved management scenarios

Figures 3a, b, c and d compare the values of the four performance indicators for the water delivery systems under the simulated scenarios ("1", "2" and "3") in comparison to the current status ("scenario 0").

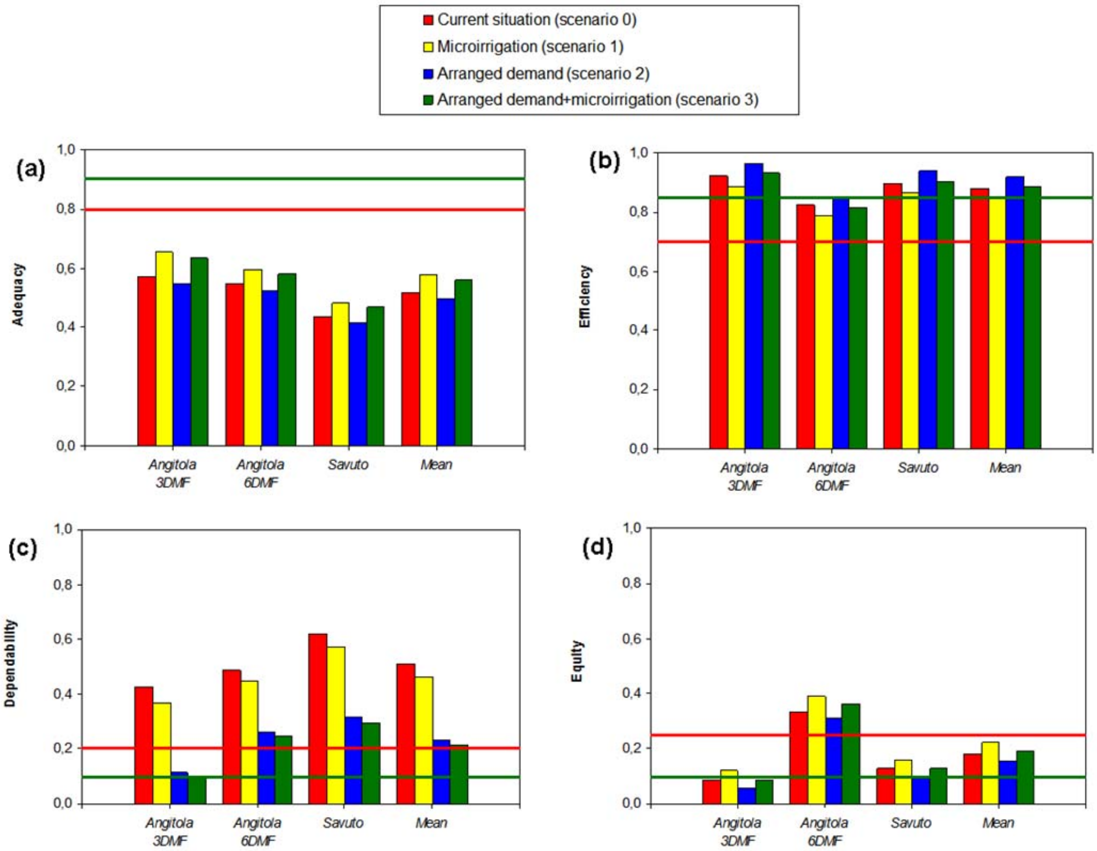

Figure 3 – Indicators of adequacy (a), efficiency (b), dependability (c) and equity (d) in the water delivery systems "Angitola 3DMF", "Angitola 6DMF" and "Savuto" under the current and the three simulated scenarios (the red and green lines show the limits "poor" and "good" respectively).

The replacement of the sprinkler systems with farm micro-irrigation ("scenario 1") increases water delivery adequacy on the average by 11%. Nevertheless, the water volume delivered is still lower than the irrigation requirement, the adequacy being in the range 0.48-0.65 (Figure 3a), thus well below the acceptance limit of 0.80; water delivery equity is reduced (increase of EQ indicator of 37%) (Figure 3d). The introduction of an arranged demand delivery system together with an irrigation advisory service ("scenario 2") induces a noticeable improvement in temporal uniformity, as shown by the average decrease in the indicator of dependability (-56%); thanks to these measures, water delivery over time becomes fair in the water delivery system "Angitola 3DMF" (DE = 0.11) and close to the fair limit (0.20) in "Angitola 6DMF" (DE = 0.26) (Figure 3c). Moreover, system efficiency feels the effects of these improvements (Figure 3b), as shown by the increased value of EF (4%); also equity in water distribution increases (EQ = -22%) (Figure 3d), although adequacy is slightly decreased (AD = - 5%) (Figure 3a). Scenario "3", combining both the previous scenarios ("1", introduction of micro-irrigation, and "2", arranged demand water delivery + irrigation advisory service), allows a simultaneous increase in adequacy (on the average +8%), efficiency (+0.4%) and dependability (by about 60%) of water delivery, in spite of a slight worsening of its equity (by 3%) (Figures. 3a, b, c, d). Compared to the current management (scenario "0"), through the introduction of the improving measures under scenario "3", it can be noticed: (i) dependability becomes good in the water delivery system "Angitola 3DMF" and is closer to the limit of acceptance (0.20) in the other water delivery systems; (ii) efficiency, previously good in the water delivery systems "Angitola 3DMF" and "Savuto", slightly improves in these systems and remains fair in "Angitola 3DMF"; (iii) in all the investigated water delivery systems adequacy noticeably increases, even though remaining below the acceptance limit of 0.80 (the maximum value of this performance indicator, equal to 0.64, is recorded in the water delivery system "Angitola 3DMF"); (iv) equity, essentially constant, is still fair in the water delivery systems "Angitola 3DMF" and "Savuto", but remains poor in "Angitola 6DMF". However, the simulated management scenarios are not expected to modify the spatial uniformity of water delivery and, therefore, other infrastructural countermeasures (i.e. limits in water supply for some farmers by introducing valves or flow regulation devices) should be introduced by the irrigation managers.

From the simulation of improved management scenarios and the related evaluations by the performance indicators, it emerges that the amount of water delivered, insufficient to satisfy the irrigation requirement in spite of the simulated improvements, must be considerably increased through further actions, in order to assure additional water volumes during the entire irrigation season. This may be achieved, for example, by diverting additional volumes from water courses and lakes, pumping groundwater from wells or using reclaimed wastewater. Another choice may be the adoption of deficit irrigation; however, since this inevitably results in plant drought stress and consequently in production loss, farmers in Calabria may be restive in its implementation, because they show a low tolerance to the consequent reduction of the agricultural yield.

On the whole, in this case of poor adequacy and dependability in water delivery systems, the comparison of the evaluated scenarios has shown that the replacement of sprinklers with micro-irrigation (scenario "1") produces lower improvements in water delivery performance compared to the implementation of an arranged demand distribution together with an irrigation advisory systems (scenario "2"). As a matter of fact, scenario "1" induces slight increases in water delivery adequacy and dependability beside decreases in efficiency and equity. Instead, scenario "2" increases slightly efficiency, but noticeably dependability and equity of water delivery, although worsening slightly adequacy. This latter performance may be a problem, since it reduces the current poor water volume delivery compared to the irrigation requirement, even though this decrease is almost limited. The combination of the two scenarios (micro-irrigation and arranged demand distribution + irrigation advisory service) is the optimal choice, since its introduction simultaneously increases water delivery adequacy, efficiency and particularly dependability - this latter more than in the individual scenarios, - in spite of a very limited decrease of equity.

4. Conclusions

The evaluation of performances of three water delivery systems in Calabria according to the guidelines of Molden and Gates (1990) has shown that in the current situation the delivered water is much lower than the monthly irrigation requirement, even though irrigation water is used without significant waste; water is never delivered in phase with the irrigation requirement, while the systems assures a delivery of fair volumes among users. As regards the evaluation of three alternative management scenarios, the introduction of arranged demand distribution and irrigation advisory service is more efficacious than the replacement of current sprinkler systems with micro-irrigation. In this case of poor service adequacy and dependability, the combined adoption of both scenarios is advisable, in order to assure the best performance of the analysed water delivery systems; it simultaneously increases three of the four water delivery performances and lets the collective irrigation service be more adequate and reliable.

References

ARSSA, 2003. I suoli della Calabria - Carta dei suoli in scala 1:250.000 della regione Calabria Rubettino Editore, Catanzaro, Italy.

Clarke, D., Smith, M., El-Askari, K., 1998. User's Guide: CropWat 4, Windows Version 4.2.0013. IDIS (UK), FAO (Italy), NWRC (Egypt), 43.

FAO, 2009. CropWat. http://www.fao.org/nr/water/infores_databases_cropwat.html.

Mateos, L., Lopez-Cortijo, I., Sagardoy, J. A. 2002. SIMIS: the FAO decision support system for irrigation scheme management. Agric. Water Manag. 56(3), 193-206.

Merriam, J.L., Styles, S.W., Freeman, B.J. 2007. Flexible irrigation systems: concept, design, and application. Journal of irrigation and drainage engineering 133(1), 2-11.

Molden, D.J., Gates, T.K., 1990. Performance measures for evaluation of irrigation water delivery systems. J. Irrig. Drain. Eng. ASCE 116(6), 804-823.

Nam Won, H., Hong Eun, M., Choi Jin, Y., 2016. Assessment of water delivery efficiency in irrigation canals using performance indicators. Irrig. Sci. 34:129-143.

Saxton, K.E., Rawls, W.J., Romberger, J.S., Papendick, R.I., 1986. Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Amer. J., 50(4), 1031-1036.

Zema DA, Nicotra A, Tamburino V, Zimbone SM (2015) Performance assessment of collective irrigation in Water Users' Associations of Calabria (southern Italy). Irrig Drain 64: 314-325.