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RESEARCH ARTICLE

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Effect of cyclic irrigation using moderately saline and non-saline water on onion (*Allium cepa* L.) yield and soil salinization in semi-arid areas of Northern Ethiopia†

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Abstract

Due to the scarcity and/or unreliability of canal water supply, seepage water is haphazardly used for sole irrigation or in conjunction with canal water in most small-scale irrigation schemes in northern Ethiopia. This has been a major cause of low crop yield and has aggravated soil salinization. The problem is more exacerbated for onion, which is the major irrigated vegetable crop and is sensitive to salinity. Thus, it is essential to assess a sustainable way to use both water resources conjunctively for the production of onion. A new study in the Ethiopian context was conducted to evaluate the effect of cyclic irrigation using non-saline canal water (EC, 0.41–0.78 dS m^{-1}) and moderately saline seepage water (EC, 0.82–2.19 dS m^{-1}) on onion yield and soil salinization for two seasons (2014/2015 and 2015/2016) in the Gumselassa irrigation scheme, Ethiopia. Four irrigation water treatments were applied with three replications consisting of: C (canal), S (seepage), 2CS (two canal and seepage) and CS (canal and seepage). In both seasons, the onion bulb yield variations between the C, 2CS and CS treatments were not significant; however, the S treatment reduced the onion yield significantly compared to all but CS in 2015/2016. The S treatment resulted in significant salt accumulation in the upper soil profile (0–20 cm). The alternate (C : S) cyclic option is thus recommended for alleviation of the problem of freshwater scarcity, without undue onion yield reduction and soil salinization in Gumselassa and similar irrigation schemes.

KEYWORDS
cyclic irrigation, Gumselassa, onion, soil salinization, Tigray

Résumé

En raison de la rareté et/ou du manque de fiabilité de l'approvisionnement en eau du canal, l'eau d'infiltration est utilisée au hasard pour l'irrigation exclusive ou conjointement avec l'eau du canal dans la plupart des petits périmètres irrigués du nord de l'Éthiopie. Cela a été une cause majeure de faible

† Effet de l'irrigation cyclique utilisant de l'eau modérément saline et non saline sur le rendement de l'oignon (*Allium cepa* L.) et la salinisation du sol dans les zones semi-arides du nord de l'Éthiopie.

rendement des cultures et d'aggravation de la salinisation des sols. Le problème est plus exacerbé pour l'oignon, qui est la principale culture légumière irriguée et sensible à la salinité. Ainsi, il est essentiel d'évaluer une manière durable d'utiliser conjointement les deux ressources en eau pour la production d'oignons. Une nouvelle étude dans le contexte éthiopien a été menée pour évaluer l'effet de l'irrigation cyclique à l'aide d'eau de canal non saline (EC, 0.41–0.78 dS m^{-1}) et d'eau d'infiltration modérément saline (EC, 0.82–2.19 dS m^{-1}) sur rendement en oignons et salinisation du sol pendant deux saisons (2014/2015 et 2015/2016) dans le périmètre irrigué de Gumselassa, Ethiopie. Quatre traitements de l'eau d'irrigation ont été appliqués avec trois répétitions comprenant: C (canal), S (infiltration), 2CS (deux canaux et infiltration) et CS (canal et infiltration). Au cours des deux saisons, les variations de rendement du bulbe d'oignon entre les traitements C, 2CS et CS n'étaient pas significatives, mais le traitement S a réduit le rendement d'oignon de manière significative par rapport à tous sauf CS en 2015/2016. Le traitement S a entraîné une accumulation importante de sel dans le profil supérieur du sol (0–20 cm). L'option cyclique alternative (C : S) est donc recommandée pour atténuer le problème de la rareté de l'eau douce, sans réduction excessive du rendement en oignons et salinisation du sol à Gumselassa et dans des périmètres d'irrigation similaires.

MOTS CLÉS

irrigation cyclique, oignon, salinisation des sols, Gumselassa, Tigray

1 | INTRODUCTION

Scarcity of fresh water especially in arid and semi-arid regions of the world has been a major challenge for irrigated agriculture. In response to the increasing scarcity of good quality water for irrigation, farmers are forced to use poor quality water such as brackish, saline or sodic groundwater, drainage water and wastewater (Feigin *et al.,* 1991; Elamin and Al-Wehaibi, 2005; Qureshi, 2014). For this reason, vast irrigation areas are threatened by salinization, yield reduction and land abandonment (Rhoades *et al.,* 1992; Szabolcs, 1994; Crescimanno and De Santis, 2004; Crescimanno, 2007; Qureshi, 2014).

Good quality water resources are diminishing, and saline water must be utilized at best without causing detrimental yield loss and environmental impact (Rhoades, 1984; Shay, 1990; Smith *et al.,* 1996). Even irrigation with good quality water under poor management can create salinization. Thus, adequate management practices are urgently needed for sustainable use of poor quality waters (Crescimanno, 2007).

The use of poor quality water for irrigation has been widely documented (for example Feigin *et al.,* 1991; Elamin and Al-Wehaibi, 2005; Minhas *et al.,* 2007). Conjunctive use of water for irrigation has been one strategy to utilize water resources where good and poor quality waters coexist and can be applied by blending or cyclic methods (Grattan and Rhoades, 1990). Blending involves mixing saline with fresh water and a cyclic method means alternate application of saline and fresh water.

Many researchers agree on the superiority of the cyclic method over blending (Sharma and Minhas, 2005; Minhas *et al.,* 2007; Singh, 2014) in that it is easier to apply and does not need a reservoir for blending, while soil salinity can also be reduced at the critical time of physiological growth allowing room for salt-sensitive crops (Grattan and Rhoades, 1990; Rhoades *et al.,* 1992; Chanduvi, 1997).

In the Tigray region of northern Ethiopia, as in other countries, seepage water from micro dams has been diverted and used directly for irrigation in many community-managed small-scale irrigation schemes, mainly due to the scarcity and/or unreliability of fresh canal water (Teshome, 2003; Hagos, 2005; Yohannes *et al.,* 2017). Depending on the local situation, seepage water is either used continuously for the entire growing season or in conjunction (in a cyclic manner) with fresh canal water with no predetermined sequences (Yohannes *et al.,* 2017).

Some studies have quoted that the use of the seepage water is one of the major causes of aggravating soil salinization and crop yield decline, especially in the Tigray region (Hagos, 2005; Yohannes *et al.,* 2017). The problem is more pronounced as the seepage water is utilized for growing salt-sensitive crops, particularly onion (*Allium cepa* L.).

Onion is one of the major high-value irrigated vegetable crops for smallholders and has wide coverage in Ethiopia. As an integral part of the Ethiopian diet, it is the most locally consumed vegetable crop and the main source of cash income for smallholders in the country and particularly in the Tigray region. Onion is a shallow-rooted crop and is sensitive to salinity. Soil salinity (ECe) above 1.2 dS m^{-1} (Maas and Hoffman, 1977; Doorenbos and Kassam, 1979; Allen *et al.,* 1998) and water salinity (EC) above 0.8 dS m^{-1} (Ayers and Westcot, 1985) generally result in onion yield reduction.

Most of the studies conducted on the onion crop in the country have mainly focused on fertilizer response, the effects of intra-row spacing or the effect of both on yield and/or yield or growth components of onion (Awas *et al.,* 2010; Abdissa *et al.,* 2011; Assefa *et al.,* 2015; Belay *et al.,* 2015; Gessesew *et al.,* 2015a, b). Despite existing practices of using poor quality water for irrigating particularly salt-sensitive crops of great importance in yield and sustainability, less attention has been given to this by the scientific community in the country and particularly in the Tigray region. Farmers in the region are constrained by lack of knowledge of, and skill in, improved irrigation water management practices, which have resulted in productivity decline and intensification of land degradation (Hagos, 2005; Ministry of Agriculture (MoA), 2011;Yohannes *et al.,* 2017;Gebremeskel *et al.,* 2018).

Generally, most of the research conducted in the country is on-station with little or no involvement of extension workers and most importantly farmers, which has resulted in very low technology generation in the field of irrigation water management (MoA, 2011). For sustainable agricultural productivity of irrigation schemes particularly in the Tigray region, appropriate management strategies that involve farmers' participation are required (Yohannes *et al.,* 2017; Gebremeskel *et al.,* 2018).

Worldwide, several pieces of research on cyclic irrigation strategy have been conducted on different crops (Rhoades, 1984; Bradford and Letey, 1992; Schaan *et al.,* 2003; Choudhary *et al.,* 2006; Murtaza *et al.,* 2006; Qadir and Drechsel, 2010). Studies on cyclic irrigation strategy for cotton, rice, wheat, sugar beet, tomato, cantaloupe and pistachio have shown sustainable production (Qadir and Drechsel, 2010). However, there is insufficient information on the cyclic irrigation of onion in semi-arid areas, where onion is one of the major irrigated cash crops.

Moreover, most of the studies conducted worldwide are in greenhouses, using artificially salinized water with the aim of establishing relationships between salinity and crop yield (e.g. Van Genuchten, 1984; Katerji *et al.,* 2001; Gandahi *et al.,* 2017). As a result the outputs did not directly serve the end users. Earlier, Evans *et al.* (2012) also reported poor achievement in conjunctive use management and its widespread implementation. Thus, practical on-farm studies involving local farmers that could influence their decisions are essential for addressing the twin challenges of sustainability and water scarcity in irrigated agriculture.

A study on the conjunctive use of water for irrigation (new of its kind in the context of Ethiopia) was conducted with the aim of assessing a sustainable way of using both fresh and moderately saline water resources for the production of onion, through a cyclic irrigation strategy. More attention was given to yield and salinity hazards. A participatory approach was used to collect farmers' opinions for further facilitation of adoption.

It is believed that this study will directly help local farmers to increase their production and further in improving equitable water allocation. It also has important lessons for local and regional decision makers, in their endeavour to address the sustainability of small-scale irrigated agriculture. Finally, this study on conjunctive irrigation can be regarded as a new breakthrough in the context of Ethiopia, and researchers in the subject matter can benefit from it as starting and guiding information in their further investigations.

2 | METHODOLOGY

2.1 | Study site description

The experiment was conducted at the Gumselassa irrigation scheme in Hintalo Wojerat *Woreda,*[1] in the southern zone of Tigray region, northern Ethiopia. The irrigation scheme is specifically located between $13^0 13'$–$13^0 15'$ N and $39^0 30'$–$39^0 33'$ E (Figure 1) with an altitude of 2000 m + MSL (mean sea level).

The major water source for irrigation is a micro-dam with a reservoir design capacity of 1.9 Mm^3 (million cubic metres) of water. The second source is seepage water that

[1]District or an administrative hierarchy below zonal administration.

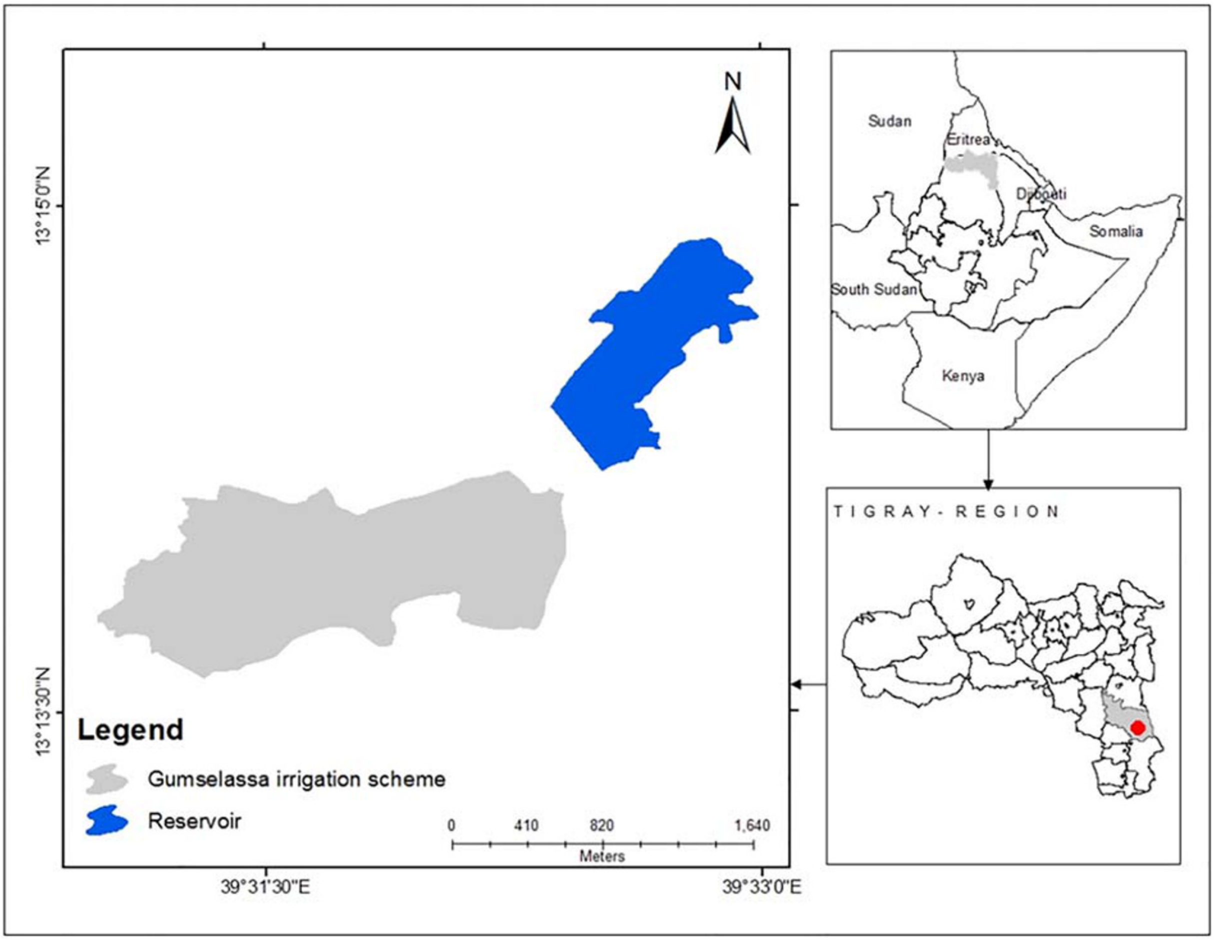

FIGURE 1 Location of Gumselassa irrigation scheme (adopted from Yohannes *et al.*, 2017) [Colour figure can be viewed at wileyonlinelibrary.com]

comes from the reservoir (through the bed and earthen dam body), which is diverted to a canal and used for irrigation. Depending on the harvested water in the dam reservoir, the size of the total irrigated area varies from year to year. According to Yohannes *et al.* (2017), based on 6 years' data (2011–2016) analysis, about 12–35% of the total irrigated area was covered by seepage water. The major soil of the scheme is clay (Table I) with poor infiltration characteristics (Hagos, 2005). Most of the irrigation schemes in the region, including the study area, are characterized by poor drainage systems (Hagos, 2005; Yohannes *et al.,* 2017; Gebremeskel *et al.,* 2018). The

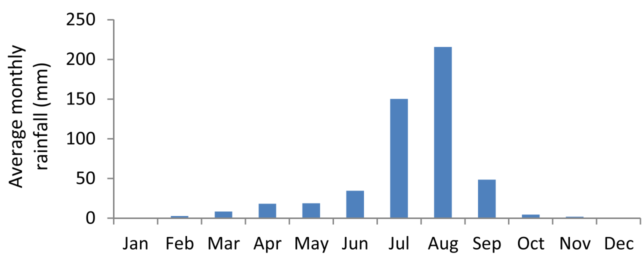

FIGURE 2 Average monthly rainfall over 43 years (1975–2017) at Adigudom station [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE I Soil properties of the experimental plot

	Particle size distribution (%)				
Soil depth (cm)	**Sand**	**Silt**	**Clay**	**Texture (USDA)**	**OM (%)**
0–20	17	28	55	Clay	2.31
20–40	15	27	58	Clay	2.00
40–60	15	25	60	Clay	1.84

Note: OM = organic matter content.

irrigated crops include maize, onion, vetch, chickpea, green pea, teff, tomato, garlic, sorghum, lentil, barley, pepper, cabbage and potato.

The annual average rainfall is 500 mm (Figure 2), and agro-ecologically the area is classified as typical semi-arid (Yohannes *et al.,* 2017).

3 | METHODS OF DATA COLLECTION

3.1 | Experimental design

The experiment was conducted for two consecutive irrigation seasons (2014/2015 and 2015/2016) from December to April.

From the farmers' fields that could be irrigated by both canal and seepage water through gravity irrigation, a fairly representative and appropriate field for the experiment was selected. The experiment was set in randomized complete block design (RCBD) with treatments replicated three times. Four water treatments were applied, comprising: C = irrigation by canal water throughout the growing period, S = irrigation by seepage water throughout the growing season, CS = irrigation by canal and seepage water in alternate cycles, 2CS = irrigation twice by canal water and a third by seepage water in a cyclic manner.

Each treatment had 10.2 m^2 (5 m × 2.1 m) plot size, containing seven rows/furrows. The border between treatments within a block was 2 m and between blocks was 1.5 m. The Adama Red onion (*Allium cepa* L.) variety, which is popular in the country and most preferred by the farmers in the study area, was selected for the experiment. The onion seedlings were transplanted with a spacing of 10 cm between plants and 30 cm between rows/furrows, which is the usual practice of the farmers' in the study area.

3.2 | Irrigation schedule

Before setting up the experimental plots, the field was irrigated using fresh canal water. The irrigation treatments were initiated at transplanting. The irrigation schedule (amount and interval) was based on national recommendations for the soils in the study area, with some adjustment to suit local conditions (Guideline on irrigation agronomy (GIA), 2011). Accordingly, 30 mm net depth at a time was applied, based on the peak demand of onion assuming little or no rainfall occurs during the growing season (GIA, 2011). Taking into consideration short (5 m) well graded and closed furrows (no runoff) and regulated discharge, 75% application efficiency was used. Then, the gross applied depth was 40 mm. For the first 3 weeks a 5-day irrigation interval was maintained, then extended to 7 days until 3 weeks before harvest. Considering the shallow crop root depth (early stage), local practices and the farmers' and local extension agents' suggestions to avoid a huge initial water loss, the gross irrigation depth applied was reduced to 30 mm for the first four irrigations, and then increased to 40 mm for the rest of the irrigation events. The crop was irrigated 17 times during the growing season and the total applied irrigation depth was 640 mm. The amount of water applied was measured using a Parshall flume.

Due to insignificant rainfall during the off-season, irrigation is practised in order to satisfy the full demand of crops in the study area. In the case of unexpected rainfall during the irrigation season, effective rainfall can be calculated by subtracting 5 mm from each of the daily rainfall totals (Sustainable Agriculture Initiative Platform (SAI), 2010). The main assumption is that rainfall of 5 mm or less is not significant during a dry period (Dastane, 1975). Then the sum of daily effective rainfall before an irrigation event can be deducted from the crop demand.

3.3 | Measurement of irrigation water using a Parshall flume

A field datasheet, an RBC (Replogle, Bos, and Clemmens) 13.17.02 flume (0.1–8.7 l s^{-1} capacity) that has a direct discharge reading, stopwatch and calculator were prepared. The water from the supply canal was allowed to flow to a drain until it stabilized, to get a constant discharge (Q). Then the total time required (T_t) to apply the desired total volume of water (V_t) was calculated instantly ($T_t = V_t/Q$). The irrigation was applied for the calculated duration. In case the Q changes while irrigating, the time would be recoded and the applied volume (V_a) is calculated (V_a = elapsed time × Q); then the remaining volume (V_r) would be computed by deducting applied volume from the total volume required ($V_r = V_t - V_a$). Then, based on the new discharge, the time required for applying the remaining volume of water would be calculated, and so on.

3.4 | Farmers' participation

As major stakeholders, farmers were invited to participate in most activities, starting from onset up to the end of the experiment in both irrigation seasons. Selection of onion variety and adjustment of irrigation schedules to the local circumstances were carried out in consultation with the local farmers and extension agents. Many farmers had taken part in preparation of the nursery and raising of onion seedlings, ploughing, diversion of irrigation water, guarding, cultivation, weeding and harvesting activities in consultation with the researchers. Two trained farmers were involved in flow measurement using the Parshall flume. During the experimental period formal and informal field visits and discussions of the vicinity farmers and local extension workers were commonly noted (Figure 3).

3.5 | Crop agronomy and management

Adama Red variety onion seeds were sown in a nursery prepared in the study area. After 50 days' intensive care, the seedlings were transplanted to the experimental plots. Based on national recommendation rates, 100 kg ha^{-1} urea and 200 kg ha^{-1} diammonium phosphate were applied. Urea was applied twice, half at transplanting and half 1 month after transplanting. Diammonium phosphate was all applied at planting. Similarly, weeding and cultivation were done as per the practices of the farmers.

4 | DATA COLLECTION AND ANALYSIS

4.1 | Water and soil data

The electrical conductivities (EC, dS m^{-1}) and pH of the canal and seepage water were monitored using portable EC and pH meters. Soil sample profiles with 20 cm depth intervals up to 60 cm were collected from each treatment at harvest and planting in both irrigation seasons. Then the samples were air-dried, crushed and sieved (2 mm sieve) in the laboratory. Following the standard method of the Soil Survey Staff (2011), the saturated paste was prepared by adding salt-free (deionized) water to the soil samples while stirring the mixture until it glistened and slid freely from a spatula. The mixture was allowed to stand overnight and rechecked for saturation criteria. For the mixtures that failed to meet these criteria, more water or soil was added until the criteria were met. Then, the water was extracted from the saturated soil using a vacuum pump. Finally, the electrical conductivity (dS m^{-1}) of the saturation extract (EC_e) was measured using an automatic temperature compensation conductivity meter and a direct reading digital bridge.

4.2 | Yield and yield components

The plant height and numbers of leaves per plant of the onion stands was recorded by randomly selecting 15 plants from the central 3 rows of each treatment. After 75% of the leaves were dried, the onion crop was harvested and cured. Fresh bulb yields were measured from the central 3 rows of the treatments. Bulb weight, diameter and length were recorded by randomly selecting 15 onion bulbs from the harvest of the central 3 rows.

4.3 | Farmers' and experts' opinions

From the major onion growers in the irrigation scheme, 15 farmers (who utilize canal, seepage and both water sources for irrigation, water user' association committees/

FIGURE 3 Farmers' and extension agents' visit to the experimental plot [Colour figure can be viewed at wileyonlinelibrary.com]

their representatives) and three local experts from the *Woreda* Office of Agriculture and Natural Resources were invited in during harvest.

Then, they were provided with four types of cards labelled with numbers from one (1) to four (4). The labelled cards were prepared with different colours to let illiterate farmers easily understand what each card stood for. The value of each card and representations were: '1' or 'Green' the best, '2' or 'Blue' the second best, '3' or 'Yellow' third best and '4' or 'Red' the worst. A short tutorial was delivered to all participants on the value of the cards and on how to use them. Then after careful observation of each block, each participant was allowed to freely rank the replications of the treatments in each block, using their own criteria. Then, a discussion too place with all the participants regarding the performance of the different treatments and their major reasons or criteria for ranking. Moreover, their concerns, comments and suggestion on the conjunctive (cyclic) irrigation strategy were collected.

4.4 | Analysis of data

Analysis of variance was performed to evaluate the effect of irrigation treatments on onion yield and yield components (total bulb yield, bulb weight, bulb diameter and length, plant height and number of leaves) using SPSS 20 statistical software, separately for each year. The mean difference was estimated using the least significant difference (LSD) comparison. Similarly, a mean comparison of the farmers' and extension agents' ranking on the different treatments for both irrigation seasons was also analysed using SPSS.

5 | RESULTS

5.1 | Water quality

The water sources used for irrigation and their qualities are shown in Table II. The EC for canal water ranged from

TABLE II The qualities of irrigation water sources (EC, dS m^{-1}) and irrigation schedules

		Irrigation season									
		2014/2015[a]					2015/2016				
Irrigation event	Irrigation depth (mm)	Date	C	2CS	CS	S	Date	C	2CS	CS	S
1st	30	10/Jan/15	0.44	0.44	0.44	1.12	02/Dec/15	0.41	0.41	0.41	0.82
2nd	30	15/Jan/15	0.44	0.44	1.11	1.11	07/Dec/15	0.39	0.39	0.85	0.85
3rd	30	20/Jan/15	0.46	1.16	0.46	1.16	12/Dec/15	0.4	0.91	0.4	0.91
4th	30	25/Jan/15	0.48	0.48	1.19	1.19	17/Dec/15	0.4	0.4	1.01	1.01
5th	40	30/Jan/15	0.49	0.49	0.49	1.21	22/Dec/15	0.42	0.42	0.42	1.13
6th	40	06/Feb/15	0.53	1.27	1.27	1.27	29/Dec/15	0.46	1.17	1.17	1.17
7th	40	13/Feb/15	0.56	0.56	0.56	1.33	05/Jan/16	0.47	0.47	0.47	1.25
8th	40	20/Feb/15	0.61	0.61	1.38	1.38	12/Jan/16	0.5	0.5	1.31	1.31
9th	40	27/Feb/15	0.63	1.45	0.63	1.45	19/Jan/16	0.52	1.48	0.52	1.48
10th	40	06/Mar/15	0.65	0.65	1.54	1.54	26/Jan/16	0.51	0.51	1.54	1.54
11th	40	13/Mar/15	0.67	0.67	0.67	1.65	02/Feb/16	0.53	0.53	0.53	1.62
12th	40	20/Mar/15	0.68	1.66	1.66	1.66	09/Feb/16	0.54	1.75	1.75	1.75
13th	40	27/Mar/15	0.71	0.71	0.71	1.74	16/Feb/16	0.57	0.57	0.57	1.84
14th	40	03/Apr/15	0.73	0.73	1.85	1.85	23/Feb/16	0.62	0.62	1.93	1.93
15th	40	10/Apr/15	0.75	2.01	0.75	2.01	01/Mar/16	0.65	1.94	0.65	1.94
16th	40	17/Apr/15	0.77	0.77	2.1	2.1	08/Mar/16	0.64	0.64	1.96	1.96
17th	40	24/Apr/15	0.78	0.78	0.78	2.19	15/Mar/16	0.65	0.65	0.65	1.96
Sum	640										

Note:
[a]The term '2014/2015' was used because pre-plant irrigation and ploughing was done in December 2014.
C = sole irrigation using fresh canal water; 2CS = irrigation twice by canal water and third by seepage water in cyclic manner; CS = irrigation using canal and seepage water in alternate cycle; S = sole irrigation using seepage water.
Samples are measured at the head of the farm gate.

0.44 to 0.78 dS m^{-1} and from 0.41 to 0.65 4–7 dS m^{-1} at planting and harvest, respectively. The corresponding values for the seepage water were 1.12–2.19 and 0.82–1.96 dS m^{-1}. Similarly, Hagos (2005) also reported high spatial and temporal EC variation of the water sources within the same cropping seasons in the same study area. The pH values showed no temporal characteristic trend (not included), but generally varied between 7.4–7.9 and 7.8–7.9 for the canal and seepage waters, respectively.

5.2 | Soil salinity

The salt distribution (ECe) profile of the different irrigation treatments at 20 cm intervals up to 60 cm, at planting and harvest of the onion crop for both irrigation seasons, are shown in Figure 4. At planting, average root zone (60 cm) soil salinities (ECe) of 1.70, 1.73, 1.76 and 1.71 dS m^{-1} were found for treatments C, 2CS, CS and S in the 2014/2015 irrigation season, respectively. The corresponding values for 2015/2016 were 1.6, 1.7, 1.6 and 1.7 dS m^{-1}.

The effect of different irrigation treatments at harvest resulted in significant variation in average soil salinities, in both irrigation seasons. At harvest the ECe of all treatments increased, especially at relatively higher magnitudes in the upper root zone, in both irrigation seasons. Although the severity varied between irrigation events and treatments, after the soil dried the appearance of white efflorescence on the soil surface was common. At the end of the growing season, lower (1.95 dS m^{-1} in 2014/2015 and 1.83 dS m^{-1} in 2015/2016) and higher (2.96 dS m^{1} in 2014/2015 and 2.94 dS m^{-1} in 2015/2016) surface (0–20 cm) ECe were found in the C and S treatments, respectively.

In the 2014/2015 irrigation season, at harvest average (0–60 cm) ECe of 1.78, 1.97, 2.28 and 2.77 dS m^{-1} were recorded in the C, 2CS, CS and S treatments, respectively. For 2015/2016, the ECe values for the corresponding treatments were 1.74, 1.85, 1.98 and 2.15 dS m^{-1}, respectively. A clear salinity build-up in an increasing order was observed from canal to combinations of canal and seepage and seepage water, as shown in Figure 4.

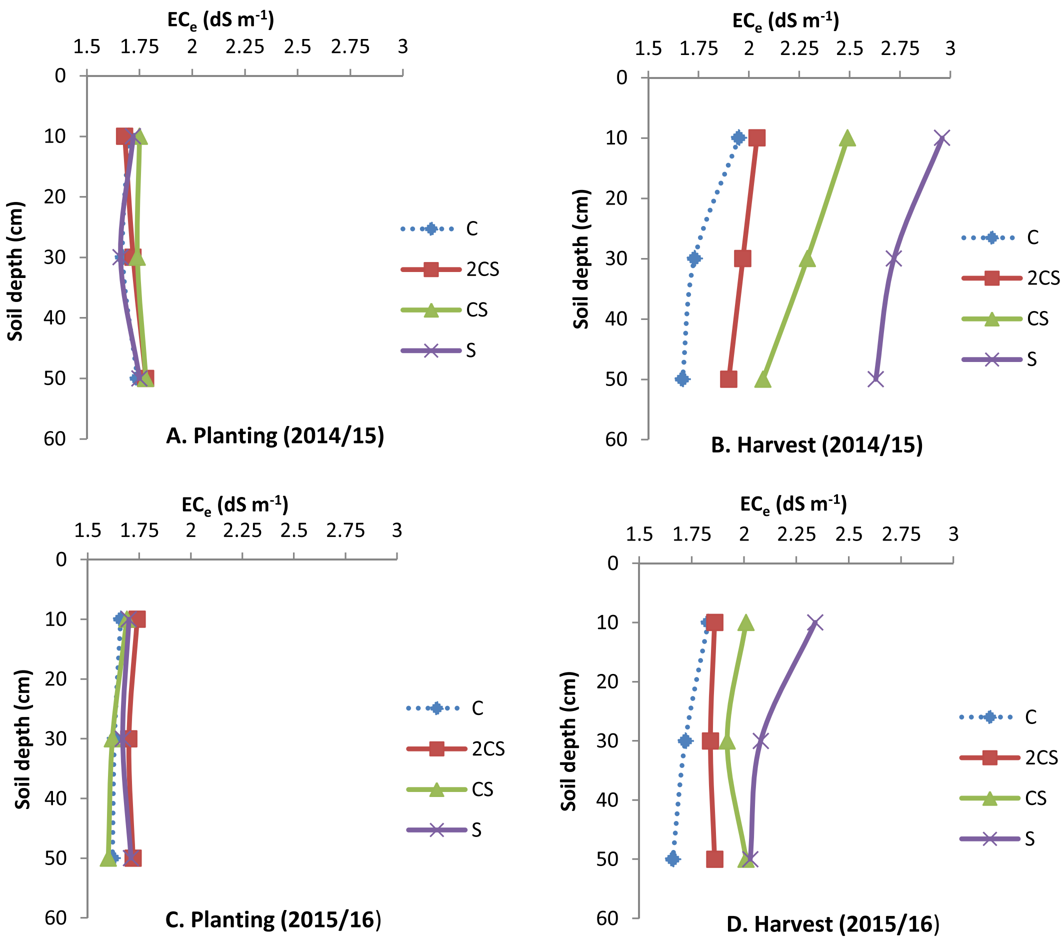

FIGURE 4 Profile distribution of salinity (ECe) of different irrigation treatments at planting and harvest of onion crop [Colour figure can be viewed at wileyonlinelibrary.com]

5.3 | Onion crop performance

The effect of different irrigation water treatments on onion bulb yield, growth (plant height and leaf number) and yield (bulb weight, diameter and length) components are given in Table III.

The effect of different irrigation water treatments resulted in significant variations in onion bulb yield. The highest bulb yield was found with continuous canal water use, whereas the lowest was with continuous seepage water use. In both irrigation seasons, maximum (23.2 t ha^{-1} in 2014/2015 and 24.8 t ha^{-1} in 2015/2016) and minimum (20.4 t ha^{-1} in 2014/2015 and 23.0 t ha^{-1} in 2015/2016) onion bulb yields were found in the C and S treatments, respectively. In both irrigation seasons, both C and 2CS treatments significantly ($P < 0.05$) increased bulb yield compared to S. However, the bulb yield variations of C and 2CS were not significant compared to CS. Bulb yield was significantly higher for CS compared to S, only in 2014/2015.

The effect of different irrigation water treatments showed significant results for onion bulb weight (BW), bulb diameter (BD), bulb height (BL) and plant height (PH) and an insignificant result for the number of leaves (LN), as shown in Table III.

In both irrigation seasons higher BW (92.3 gram (g) in 2014/2015 and 99.6 g in 2015/2016) were recorded in treatment C. However, these values were not significantly different from 2CS and CS in both irrigation seasons. The lowest average BW (72.9 g in 2014/2015 and 86.0 g in 2015/2016) was found in treatment S, and BW variation was statistically significant compared to all treatments in 2014/2015 and to treatments C and 2CS in 2015/2016.

As shown in Table III, the effect of different irrigation treatments on average BD was significant in both irrigation seasons. Maximum BD was found in C (5.71 cm in 2014/2015 and 6.6 cm in 2015/2016), followed by 2CS (5.69 cm in 2014/2015 and 6.53 cm in 2015/2016). The BD variations between C and 2CS and between CS and S in 2014/2015 were statistically similar, although the former treatments resulted in significantly higher BD compared to the latter treatments. In 2015/2016 the S treatment resulted in significantly lower BD compared to C and 2CS; however, it was statistically similar compared to CS.

The variations of bulb length (BL) were significantly affected by the application of different irrigation treatments in both irrigation seasons. Maximum average BL (6.57 cm in 2015/2016) was found in C and minimum (4.97 cm in 2014/2015) was found in S. In both irrigation seasons significantly higher BL was found in C compared to CS and S; however, BL in C was not significantly different from 2CS. The BL in 2CS was statistically similar compared to CS in 2014/2015; however, they were significantly different in 2015/2016. In both irrigation seasons, the lowest BL was recorded in the S treatment, which was significantly different compared to all treatments in 2015/2016 and only to C and 2CS in 2014/2015.

The effect of different irrigation water treatments resulted in significant variations in plant heights (PH) in 2014/2015 but they were statistically similar in 2015/2016. The tallest plants were recorded in C (54 cm) followed by 2CS (51.9 cm) in 2014/2015, and the variation in PH of both was significant compared to S. In the same season, the shortest plants were found in S (45.9 cm), although these lengths were statistically similar compared to CS (49.3 cm). In the second irrigation season (2015/2016), the tallest PH (56.8 cm) was recorded in treatment C, which was statistically different from all treatments.

Maximum (12.2 in 2014/2015 and 12.9 in 2015/2016) and minimum (10.8 in 2014/2015 and 11.9 in 2015/2016)

TABLE III Effects of irrigation water treatments on onion yield and yield components

Irrigation season	Treatment	TBY (t ha^{-1})	BW (g)	PH (cm)	LN	BD (cm)	BL (cm)
2014/2015	C	23.2a	92.3a	54.0a	12.2a	5.71a	6.33a
	2CS	23.1a	90.6a	51.9a	11.7a	5.69a	5.88ab
	CS	22.4a	85.2a	49.3ab	11.3a	5.08b	5.47BC
	S	20.4b	72.9b	45.9b	10.8a	4.81b	4.97c
2015/2016	C	24.8a	99.6a	56.8a	12.9a	6.6a	6.57a
	2CS	24.7a	97.0ab	55.7a	12.8a	6.53a	6.47a
	CS	24.0ab	92.2BC	54.9a	12.1a	5.73ab	5.87b
	S	23.0b	86.0c	51.8a	11.9a	5.1b	5.2c

Note: TBY= total bulb yield, BW = bulb weight, PH = plant height, LN = leaf number, BD = bulb diameter and BL = bulb length.
Means followed by the same letters in column are not statistically different at $P < 0.05$.

number of leaves (LN) were recorded in treatments C and S, respectively. However, the variations of LN among all the treatments were statistically similar in both irrigation seasons.

5.4 | Farmers' and extension agents' opinions

The farmers' and extension agents' mean rankings of the crop stand at harvest are presented in Table IV. Results of the farmers' ranking of treatments were significant and similar in both irrigation seasons. The highest (1.47 in 2015/2016) and lowest (4 in both irrigation seasons) rank were found in C and S, respectively. The rank of C was significantly better compared to CS and S in both irrigation seasons. However, it was statistically similar compared to 2CS for both irrigation seasons. The mean rank for treatment S was the lowest and it was significant compared to all treatments in both irrigation seasons, except for CS in 2015/2016.

Based on the average mean ranking of the local experts, the treatments were prioritized in decreasing order of: C, 2CS, CS and S for both irrigation seasons (Table IV). The mean rank variations between 2CS and CS were statistically similar, however significantly higher compared to both CS and S in both irrigation seasons. The mean rank for treatment S was the lowest and significant compared to all treatments in both irrigation seasons.

From the open discussions, their major criterion for ranking the treatments was bulb size, by judging the anticipated total bulb yield. The second criterion was the difference in the magnitude of visible surface salt efflorescence from their personal observations.

The other point raised by farmers and local experts was the capacity of the irrigation committee on planning and fair allocation of the different water sources among the farmers, as well as the issue of rules and regulations for effective implementation of cyclic irrigation.

TABLE IV Farmers' and experts' mean rank of the treatments crop stand for 2014/2015 and 2015/2016 irrigation seasons

Irrigation season	Treatment	Farmers' rank	Experts' rank
2014/2015	C	1.47a	1.33a
	2CS	1.58a	1.67a
	CS	3.07b	3b
	S	3.89c	4c
2015/2016	C	1.6a	1.57a
	2CS	2ab	1.67a
	CS	2.49b	2.78b
	S	3.91c	4c

Note: small rank number represents the best.
Means followed by the same letters in column are not statistically different at $P < 0.05$.

6 | DISCUSSION

Continuous application of canal and seepage water resulted in the lowest and highest root-zone salt accumulation at the end of both irrigation seasons, respectively. The 2CS treatment resulted in the second-lowest salt accumulation followed by the CS treatment. Since the amount of irrigation water applied was the same for all treatments, the difference in magnitude of salt accumulation is attributed to the quality of the irrigation waters utilized and the application frequency (for the cyclic treatments) of seepage water. Similar results were reported by Amer (2010) and Chauhan *et al.* (2005). The highest salt accumulation in the S treatment is also in agreement with the findings of Hagos (2005), who reported higher salt accumulation in that part of the command area irrigated solely by seepage, as compared to the area irrigated by fresh canal water from his scheme-wise assessment in the same study area. This confirms that continuous use of seepage water for irrigation has been the major factor in soil salinization in the study area.

Although the magnitude varies, the highest soil salinities were found in the upper profile of all the treatments. This could be due to evaporative concentration of salts at the surface attributed to the poor internal drainage of the clay soil (Table I) and capillary rise from lower soil profiles. In particular, the increase in surface salinity for treatment S, compared to the initial condition, ranged from about 38% in 2015/2016 to 72% in 2014/2015. Onion is a shallow-rooted crop and most of its root water extraction takes place in the upper part of the rooting depth (Ayers and Westcot, 1985). This indicates that continuous use of seepage water for irrigation has been the major factor in decline of onion yields in the study area.

Salinity decreased bulb weight, bulb diameter, plant height and number of leaves per plant. However, from the mean comparison (Table III), insignificant variation in the growth components (number of leaves per plant in both irrigation season and plant height in 2015/2016) was observed compared to the yield components (bulb weight, diameter and length) across the treatments. These indicated that the yield components seem relatively more affected by the irrigation treatments compared to the growth components. This might be mainly due to the relatively lower salt concentration of the seepage water (1.12 dS m^{-1} in 2014/2015 and 0.82 dS m^{-1} in 2015/2016) at the establishment and earlier vegetative growth stages of the crop. Then, the rising EC of the water may have affected bulb enlargement more due to osmotic problems and associated nutritional effects, particularly in the S treatment. Compared to S, the higher bulb yield in CS is mainly due to the dilution effect of the canal water which consequently lowers the adverse effects of salt on the crop.

The lower salt concentration found at planting compared to at harvest in both irrigation seasons indicates leaching of salts during the rainy season and to some extent due to pre-plant irrigation. The drop in soil salinity in the irrigation scheme after the rainy season is also in agreement with the findings of Hagos (2005). Although the initial salinities dropped, the salinity levels in all cases were still higher than the threshold (1.2 dS m^{-1}) where onion yield starts to decline (Maas and Hoffman, 1977). This may have a negative effect on crop performance across all the treatments. However, sole utilization of seepage water for irrigation would exacerbate root zone salinity and subsequently have an impact on yield.

The overall performance of the crop was better in all treatments in 2015/2016 compared to the corresponding treatments in the 2014/2015 irrigation season. This is attributed to the lower initial soil salinity in 2015/2016 compared to 2014/2015. For the same reason, similar results were reported by Nagaz *et al*. (2012).

In a study conducted in the same irrigation scheme, Yohannes *et al*. (2017) reported different perceptions on the quality of irrigation water sources, between and within a group of farmers who utilize canal, seepage and both sources of water for irrigation. However, from this study, the local farmers' and extension agents' mean rank comparisons were more or less similar to the findings described in section 3.5 of this study. The study indicated that the farmers directly understood the effect of the treatments on onion yield and indirectly the qualities of the irrigation water sources. Moreover, the nature of the study which was on-farm and the farmers' involvement and continuous observations would facilitate enhancement of their practical knowledge on how to utilize conjunctively the existing irrigation water sources for production of onion. Farmers' participation in irrigation management is widely accepted as an effective means of enhancing their knowledge of irrigation (Qiao *et al.,* 2009) and facilitates further adoption of promising technologies locally.

The limited capacity of the irrigation committee on arranging planned conjunctive (cyclic) irrigation, equity and institutional aspects were the major concerns raised by farmers and local experts. It is a universal issue that farmers need capacity building in technical and institutional issues to improve the performance of irrigation schemes (World Bank, 2006; Kazbekov *et al.,* 2009; MoA, 2011; Ghazouani *et al.,* 2012; Mutambara *et al.,* 2016). Thus, building institutional capacity and technical skill of water users' associations in particular, on planning and fair allocation of different water sources among the farmers as well as the issue of rules and regulations should be considered for effective implementation of planned cyclic irrigation. Finally, the study is a major breakthrough in further assessment and study of the unrecognized conjunctive irrigation practices in Ethiopia.

7 | CONCLUSIONS

Direct use of seepage water for irrigation has been the major cause of crop yield decline and expansion of soil salinization problems in Ethiopia. A 2-year (2014/2015 and 20115/16) on-farm study was conducted to evaluate the effect of cyclic irrigation using moderately saline (seepage, 0.82–2.19 dS m^{-1}) and non-saline (canal, 0.41–0.78 dS m^{-1}) water on onion yield and soil salinization, under surface irrigation in the Gumselassa irrigation scheme, northern Ethiopia.

Continuous irrigation with canal water resulted in lower root-zone salt accumulation and highest bulb yield. On the other hand, irrigation solely with seepage water resulted in significant onion yield reduction and higher surface (0–20 cm) salt accumulation. The yields obtained using cyclic irrigations (2CS and CS) were not significantly different compared to entirely canal irrigation water use. Results of the study showed that root-zone salinity increased with increasing salinity of water sources and frequency of application of seepage water. The treatment yield declines did correspond with increasing soil salinity. The local farmers' and extension agents' overall opinions of the performance of the treatments also revealed least preference for the S treatment.

Alternate (1 : 1) cyclic application of canal and seepage irrigation water could, therefore, be considered a practical method for onion cultivation in the Gumselassa irrigation scheme and other schemes with similar challenges. Further, it could also be a promising option for improving the equity of canal water between head reach and tail-end farmers in the irrigation scheme.

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