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Nitrate Leaching under Farmers' Fertilizer and Irrigation Water Use in the Central Rift Valley of Ethiopia

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Authors' contributions

This work was carried out in collaboration between all authors. Author DA designed the study, wrote the protocol, managed the field work, performed the statistical analysis, and wrote the first draft of the manuscript. The co-authors read the proposal and the manuscript and gave feedback for the improvement of the study. All authors read and approved the final manuscript.

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ABSTRACT

In conventional furrow irrigated agriculture, excess water often causes leaching of nitrate-nitrogen. This experiment was aimed at quantifying nitrate leaching under farmers' fertilizer and irrigation water use practices. It involved factorial combination of four rates of nitrogen fertilizer (0, 92, 184, and 368 kg N ha^{-1}) and two levels of irrigation (100% crop water requirement =1.00 CWR and farmers' practice =1.25 CWR). It was conducted in onion (*Allium cepa* L.) planted drainage lysimeter at Melkassa Agricultural Research Center in 2015/16 cropping season. Nitrogen loss for the production season was determined from leachate collected every 10$\pm$3 days interval. Nitrogen

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uptake, dry matter (DM) accumulation, bulb yield, and bulb storability were measured. The result indicated low nitrate leaching for the season (< 22.46 kg NO_3^- ha^{-1}) however the losses were three-fold higher in high fertilizer rates or high irrigation water level. Independent t-test showed no significant difference ($P \geq 0.05$) between irrigation levels on total N uptake, DM accumulation, and marketable bulb yield. Significant differences ($P<0.05$) were recorded between any different sub groups of N fertilizer rates on total N uptake except between 92 and 184 kg N ha^{-1}. The significant difference between 184 and 368 kg N ha^{-1} on N uptake was not reflected in the DM accumulation and marketable onion bulb yield indicating low N use efficiency. The result showed about 48.5 to 69.4% surplus N accumulation in soil due to use of high rates of N fertilizer. Higher storage loss was depicted for application of 184 and 368 kg N ha^{-1}, and 1.25 CWR. Irrigating at 1.00 CWR and N fertilizer not exceeding about 184 kg N ha^{-1} can reduce the problem without yield reduction. However, further field study is suggested within soils that have been under irrigated vegetable production for the last many years to reach at comprehensive conclusion and management recommendations.

Keywords: Nitrogen fertilizer; nitrate leaching; onion; irrigation; central rift valley.

1. INTRODUCTION

Leaching of nitrate to surface and groundwater is among the negative impacts of the continuing increase and overuse of chemical fertilizers in furrow irrigated agriculture across the globe [1–3]. Fertilizer application rate and method, crop removal capacity, precipitation or irrigation water level, and soil texture are among the factors affecting nitrate leaching [3–7]. Lower recovery of nitrogen (N) fertilizers [8] and year-round production of irrigated agriculture favours accumulation of surplus N in the soil. The excess N accumulating in the soil system below root zone is liable to leach and is a potential threat to water body in the surrounding [1,2,9].

In the past 10 to 15 years, fertilizer use per hectare in irrigated agricultural land in the Central Rift Valley (CRV) of Ethiopia has continuously increased. An assessment study of farmers' fertilizer use in the area depicted that over 45 and 36% of onion and tomato growing farmers, respectively, used at least 184 kg N ha^{-1} [10]. Similarly, farmers' input use monitoring study in two districts, viz Adami Tulu Jiddo Kombolcha (ATJK) and Dugda of the CRV revealed that about 209 and 155 kg ha^{-1} N was the average application rates for onion and tomato production, respectively [11]. Export-oriented large-scale vegetable production and floriculture companies in the area [12,13] use more significant rates of fertilizers than the small-scale irrigated agricultural producers [12,14].

Except for floriculture and export-oriented large-scale vegetable productions, most farmers in the area use furrow irrigation that often favours deep percolation losses. Excess application of irrigation water over 40-65% of the required amount was reported for farmers producing tomato and onion in Dugda District [15]. This excess irrigation water can result in significant leaching of nitrate [16,17]. Onion being a shallow-rooted crop and predominantly produced in the CRV of Ethiopia, it is likely that this production system is creating excess N in soil liable to leaching. Larger nitrate concentrations recently found in a borehole and hand-dug wells, and Lake Zeway water (own analysis) compared to previous studies [18–20] may be among the indicators of the existence of 'leaky' production system in the area.

Despite these facts of irrigated agricultural production system in the CRV of Ethiopia, no study, to the best of our knowledge, has attempted to estimate the amount of nitrate leached from the system. Researches and review work addressing nitrate leaching from irrigated agriculture in the tropics and subtopics are scarce [2]. Investigating the status of nitrate leaching from the irrigated agricultural production system in the study area is not only one step forward towards the development of efficient nutrient and water management strategies but also is essential for the establishment of environment-friendly sustainable production system [1,21].

In the past decades, concerns over nitrate levels in surface and groundwater have led to increased efforts towards development of methods for direct monitoring of nitrate leaching. Drainage lysimeter is among the different methods employed to assess nitrate leaching in soils and has shown considerable potential for better understanding and monitoring of nitrate leaching dynamics [22–25]. Drainage lysimeter is advantageous in that it captures the entire leachate volume to be used to calculate N load passing below a specific soil depth. Hence, this study was designed to quantify the nitrate leaching under farmers' fertilizer and irrigation water use practices. The work will contribute towards maximising the benefits from irrigated agriculture development effort of the country while minimising the total environmental impact.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted at Melkassa Agricultural Research Center (MARC), located in the semi-arid regions of the CRV of Ethiopia at about 110 kilometres from Addis Ababa on the way to Assela town. Geographically, the experimental plot in the center is located at 8º25’07.1’’N and 39º19’22.6’’E at an elevation of 1557 meters above sea level (m.a.s.l). The long-term mean annual total rainfall at MARC weather station, located within less than 0.25 km from the experimental field, is 818 mm with erratic distribution. The main rainy season is from June to September. The annual average minimum and maximum temperatures are 13.8 and 28.7ºC, respectively (Fig 1). The soil type of the experimental site is well-drained loam soil genetically classified as Mollic Andosols [26].

2.2 Methodology

2.2.1 Crop management and treatments

The experiment was conducted in a drainage lysimeter (8 in number) having dimensions of 1.5 m soil depth on 2x2 and 2x1 m^2 area, at MARC from December 20, 2015 to April 16, 2016. The rim of each lysimeter protrudes 10 cm above the soil surface so that no surface water run on and runoff may occur. Four rates of N (0, 92, 184 and 368 kg of N ha^{-1}) from urea fertilizer with two irrigation water application levels (farmers practice and Crop evapotranspiration (ETc) for the test crop) were used to evaluate the fate of applied N. Excess application of irrigation water by about 40-65% was reported from farmers’ field study for tomato and onion production in Dugda District [15]. The study included the conveyance losses particularly in the secondary and tertiary canals. Conveyance loss up to 40% was reported, for instance, in Haleku Melka-Tesso irrigation project located in ATJK District [27]. Preliminary own measurements made on three onion producing farmers’ fields using Parshall flume [28] showed about 34% (6 to 51.8%) higher application than the actual water requirement for onion bulb production. Based on these observations, about 25% higher water application (1.25 CWR) (average) was assumed as representing most farmers’ irrigation water use practice.

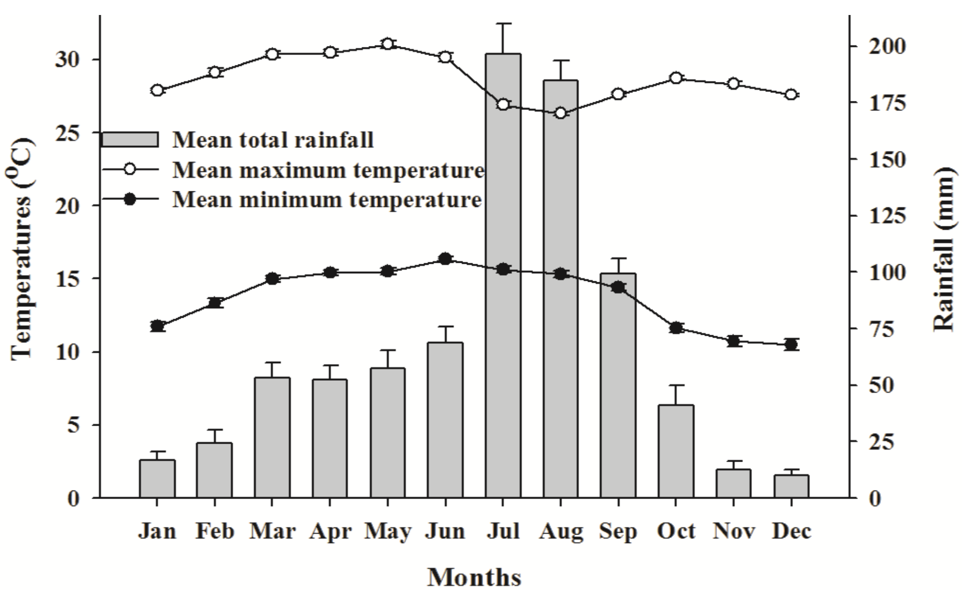

Fig. 1. Historical (1977-2015) mean monthly (temperature and rainfall) of the study area

The treatment combinations (I=0N-1.00 CWR, II=92N-1.00 CWR, III=184N-1.00 CWR, IV=368N-1.00 CWR, V=0N-1.25 CWR, VI= 92N-1.25 CWR, VII=184N-1.25 CWR, and VIII=368N-1.25 CWR) were arranged randomly to the eight lysimeter plots. Soil moisture was measured every two days using calibrated neutron probe [29]. Probe readings were taken for two depth intervals, 15–30, and 30–45 cm. For the 0-15 cm depth, gravimetric reading was used because moisture measurement near surface is not reliable with the neutron probe used in this experiment [29]. Irrigation was applied when about 25% of available soil moisture has been depleted from effective root zone [30]. For each plot, the depletion was converted into volume. Then, irrigation water was applied into the furrows based on threshold values of soil moisture for improved irrigation practice plots, while 25% extra amount was applied to the plots receiving farmers' irrigation practice. The amount of irrigation was dependent on the growth stage of the crop and weather.

Thirty-five days old seedlings of onion (*Allium cepa*) *Adama red* variety were transplanted to the lysimeter plots on December 20, 2015. At transplanting, inter- and intra-row spacing of 30 and 8 cm, respectively, was used that gives a total plant population of 412,493 plants ha^{-1} assuming that about 1% of land will be assigned to paths between terraces. Nitrogen fertilizer application was done in three splits; the first 25% at transplanting, the second 25% at 26 days after transplanting, and the remaining 50% at 26 days after the 2nd application date. Non-limiting rates of phosphorus (60 kg P ha^{-1}) from triple super phosphate and potassium (41.5 kg K ha^{-1}) from potassium sulfate (K_2SO_4) were applied at transplanting to all treatments. All required agronomic and other crop management practices other than the treatments were performed as per recommendations for the test crop. Irrigation was terminated in all the plots as onion begun to mature and tops started to fall for about 50% of the population.

2.2.2 Data collection, management, and laboratory analysis

Before treatment application to lysimeter plots, soil samples were collected from 0-15, 15-30, and 30-60 cm depths for analysis of selected soil properties. The samples were air-dried and ground to pass through a 2-mm sieve before analysis. Water holding capacity of the soil at FC (-0.33 bars) and PWP (-15 bars) were determined by pressure plate [31]. Bulk density was determined from undisturbed core samples [32]. The results of these soil analyses in combination with regularly measured soil moisture during the experimental period were used in determining irrigation water requirement for the test crop. Plant available water capacity (PAWC) was calculated as the difference between FC and PWP (PAWC= FC-PWP). Soil particle size distribution was determined by the Bouyoucos hydrometer method [33]. Soil pH and electrical conductivity (EC) were measured in supernatant suspension of 1:2.5 soil-water mixture by pH-meter [34] and conductivity meter, respectively. Organic carbon was determined following the modified Walkley and Black wet digestion method [35] and the total N by Kjeldahl procedure [36]. Available phosphorous was determined following the Olsen method [37] after extraction with sodium bicarbonate solution (pH 8.5).

Lysimeters were constructed of reinforced concrete. The inside of the lysimeters were lined with plastic sheet to avoid any leakage or lateral inflow. The natural vertical soil sequence was carefully maintained while filling the lysimeters with soil from the nearby locations in March 2012. Before the start of this experiment, lysimeter plots were saturated with irrigation water at weekly interval three times and allowed to drain to decide the frequency of retrieving the leachate. The process was also used to establish uniform soil moisture across the plots. Accordingly, the leachate collection during the experimental period was made every 10$\pm$3 days interval. Leachate volume was determined volumetrically and sub-samples from each leachate were used for laboratory determination of nitrate. The collected leachates were stored in dark cold room (4ºC) for short time (<48 hours) after sampling as immediate laboratory analysis was not possible [38]. The concentration of NO_3^- was determined by spectrophotometer as outlined in APHA [38]. The concentration of NO_3^- in irrigation water was also determined three times during the experimental period.

Simple nitrogen balance of the soil, the total N inputs minus total N outputs expressed in kilogram of N ha^{-1} per season, was estimated using Equations 1 and 2 [1,39,40]:

$$SoilNbal^1 = Napp - (Next + Nleach + Nvol) \quad (1)$$

where, *Soil N bal*^{1} = soil N balance (amount of N accumulated or depleted at harvest) when soil

organic matter mineralization was not considered.
N app =N applied to the plots (this includes the amount of N applied from fertilizer and from irrigation water)
N vol =N loss as ammonia volatilization
N ext =total N extracted and accumulated in plant dry matter at harvest (in this case onion bulb, pseudo stem and leaf)
N leach = Nitrate-N leached during the growing period

$$Soil N bal^2 = (Napp + N\min) - (Next + Nleach + Nvol) \quad (2)$$

Where, *Soil N bal*^{2} = soil N balance (amount of N accumulated or depleted) at harvest considering soil organic matter mineralization.
N min = N mineralized during the growing period; this was assumed to be the sum of N leach and N *ext* minus N applied from irrigation water in non-fertilized plots.

Data on the amounts of N losses by ammonia volatilization was not found for the agricultural production system of the country. Five percent of the applied N was assumed to be lost by ammonia volatilization considering literatures elsewhere [41–46] and the study area climate, soil, and production practices.

Leaf area measurement was made using leaf area meter (L1-3100C) on five whole-plant samples per plot at 63 and 85 days after transplanting (DAT) to determine leaf area index (LAI). Five plant samples per plot on 39, 85, and 117 DAT were collected and separated to bulb and above ground biomass. The samples were cut in to small pieces, air dried and then dried in forced-ventilated oven at 75ºC to constant dry weight. Then, the dry matter (DM) accumulation, and N uptake according to Kjeldahl laboratory procedure [36] for each treatment were determined separately for bulb and above ground (leaf and stem) part. The specific selected DATs were to represent developmental, mid, and late growing stages of the crop. Previous studies on the test crop divided the growing period in to 20, 35, 35, and 20 days of growth stages representing the initial, development, mid, and late stage, respectively [47,48].

At harvest (117 DAT), internal 4 rows were used to quantify bulb yield. Injured and small bulbs less than 20 mm diameter were recorded separately as unmarketable yield [49]. Five plant samples from the harvest were used for DM and N uptake determination. Based on the DM accumulated and total N uptake, the plant N uptake per hectare was calculated (total plant population of 412,493 plants ha^{-1}) for each treatment. Harvest index (HI) was calculated at harvest as the ratio of bulb dry matter to the total dry matter yield [50]. Irrigation water productivity (IWP) was determined in kg m^{-3} as ratio of fresh total onion bulb yield to the volume of irrigation water applied [51,52]. Nitrogen use efficiency (NUE) comprising two main components, N recovery (REC), and use efficiency of the absorbed N was determined according to Equations 3 and 4 [53]:

$$NREC\ (\%) = \frac{(Nupt_f - Nupt_u)}{N_f appl} \times 100\ \% \quad (3)$$

where *NREC (%)* = percent of N recovery
$Nupt_f$ = total N uptake by onion bulb and leaves (kg ha^{-1}) in fertilized plot
$Nupt_u$ = total N uptake by onion bulb and leaves (kg ha^{-1}) in unfertilized plot
$N_f appl$ = total N applied from fertilizer (kg)

$$NuptUE\ (Mg\ kg^{-1}) = \frac{Ey}{Nupt} \quad (4)$$

where *NuptUE* = N absorbed (uptake) use efficiency
Ey = economic (total fresh onion bulb) yield (Mg)
Nupt = N accumulation both in leaf and bulb of onion (kg)

To determine the influence of the different rates of N fertilizer application rates and irrigation water levels on bulb storability, randomly taken bulbs with sample size of 2206.08 ± 0.86 g from each treatment were stored in ventilated room for 45 days. The day time measured average temperature and relative humidity of the storage room was 28.71ºC and 70.57%, respectively. The stored bulbs were weighed and numbers of bulbs getting rotted were recorded every 15 days during the storage period to estimate loss in marketable yield.

2.2.3 Statistical analysis and interpretation

Dependent variables including total leachate and NO_3^- loss, total N-uptake, total DM accumulation, and bulb yield data were subjected to Shapiro-Wilk normality test and equality of variances using SAS software. The data did not significantly depart from normality and equality of variances. Then, the significant difference of the two irrigation water levels as well as any two sub groups of fertilizer application rates on the above mentioned dependent parameters were assessed using an independent samples t-test at alpha < 0.05. Cumulative leachate and cumulative NO_3^- leaching over the growing period as affected by irrigation water levels and N fertilizer rates was graphically presented. Descriptive statistics were also used to show onion bulb yield and other parameters contributing to bulb yield.

3. RESULTS AND DISCUSSION

3.1 Soil Characteristics

The physical and chemical properties of the lysimeter plot soils are given in Table 1. The soil textural class is loam and the bulk density was within good range for adequate plant root development [54]. The soils were moderately alkaline in their reaction and had moderate organic carbon (OC) and low total nitrogen (N) content, while the Olsen available P content of the soils was moderate to high [55].

3.2 Irrigation and Leachate

Total amount of water used for irrigation and amount of it leached below 1.5 m soil depth for each treatment assigned to the lysimeter plots are presented in Table 2. For the plots that received 1.00 CWR, the applied irrigation water was within the range of the previous studies' recommendation for onion bulb production at MARC [47,48]. Percent leachate was very close among the plots that received similar irrigation water levels except for treatment VII. These close values of percent leachate indicate the uniformity of the drainage characteristics of the lysimeter plots [25]. The total irrigation water demand for a plot that received treatment VII was exceptionally low and no leachate was received below 1.5 m soil depth. Before the experimental treatments were assigned, irrigation water of same amount was applied to each lysimeter plot to check the drainage characteristics of the plots. This was repeated every week and the weekly cumulative leachate collected were comparable and was assumed sufficient to start the experiment. The probable reason for this unusual result in the lysimeter that received treatment VII could be due to later created cracks that allow side leaks somewhere above 1.5 m soil depth. The rift valley soils are known for their fragile nature.

Comparison of total leachate using independent t-test showed significant difference between the plots that received 1.25 CWR and 1.00 CWR (t (df) =-6.7, P< 0.01) (Table 2 & Fig 2). With advancing growth stages of the crop, the amount of irrigation water required increased, which is expected and is in line with the previous finding [47]. With this, the amount of the 25% extra irrigation water that gets larger and larger will predominantly contribute to more leachate loss besides losses by evaporation from the surface and evapotranspiration.

Table 1. Selected physical and chemical properties of soils in the lysimeter plots

Soil characteristics	Depth (cm)		
	0-15	**15-30**	**30-60**
Particle size distribution (%)			
Sand	38	38	40
Silt	36	38	36
Clay	26	24	24
Textural class	**Loam**	**Loam**	**Loam**
Soil bulk density (g cm^{-3})	1.12	1.23	1.17
Water content (%w/w) at:			
Field Capacity (FC)	27.30	29.47	29.32
Permanent Wilting Point (PWP)	14.72	15.29	16.21
Plant Available Water Capacity (PAWC) (mm/m)	140.89	174.41	153.39
pH-H2O (1:2.5)	8.30	8.31	8.18
EC (1:5) (dS m^{-1})	0.20	0.22	0.27
OC (%)	1.17	1.18	1.12
Total N (%)	0.11	0.11	0.10
Olsen Available Phosphorus (mg kg^{-1})	21.97	20.78	12.97

The cumulative leachate obtained, 4.4 and 33.0 mm (Table 2 & Fig 2a), respectively for the 1.00 CWR and 1.25 CWR at harvest, was low compared to values in other literatures elsewhere; for instance 54 to 129 mm in northern China [1]. This could be attributed to the relatively shorter growing period, soil texture (loam), and higher temperature and evapotranspiration of the study area and study period (January to March). Evapotranspiration (ETo) at MARC was 446.6 mm as quantified by CROPWAT from the study period weather data.

3.3 Nitrate Loss with Drainage Water

The cumulative NO_3^- leached over the sampling dates was continuously higher by more than 2.5 folds for the plots that received 1.25 CWR compared to the 1.00 CWR regardless of the amount of N applied (Fig. 3c). The result further indicated higher amount of N fertilizer application pooled over the different irrigation water levels also resulted in higher cumulative amount of nitrate leaching (Fig. 3d) except for the lysimeter plot that received 184 kg N ha^{-1}. For the 184 kg N ha^{-1}, the data presented is only for the plot that received 1.00 CWR as that of 1.25 CWR had defect due to the probable reason earlier indicated. Considerable increase in concentration of NO_3^- in the leachate water (Fig. 3a) and hence higher losses (Fig 3b-d) were depicted particularly during sampling dates following split application of N fertilizer.

The increase in loss of NO_3^- for non-fertilized plots on the other hand followed the irrigation water influence (Fig. 3a and b). The concentration of NO_3^- in irrigation water (18.91 mg L^{-1}) is probably another contributing factor for the increasing loss of NO_3^- observed in non-fertilized plots. Different studies showed that the amount of N leached is mostly influenced by residual soil NO_3^- and the flow rate of infiltrating water which are in turn a function of numerous aspects including N fertilizer rate, water input (irrigation and/or precipitation), soil properties, climatic conditions and management [3–7,23,56].

The overall amount of total nitrate leached in this experiment, even for the higher rates of N fertilizer, was relatively low compared to the findings of other studies elsewhere. For instance, different studies based on direct quantification and model prediction of irrigated and rain-fed agriculture showed larger loses (40-347 kg N ha^{-1}) by leachate [1,2,23,57]. On the other hand, lower amount of nitrate leaching, comparable to the current finding, was reported using ion-exchange-resin cartridges in urban gardens of Niamey, Niger [3]. The lower value of NO_3^- leaching in the current experiment could be attributed to the lower amount of leachate obtained from the plots (Table 2) probably due to high temperature that possibly caused high evapotranspiration [7,58].

It was also indicated in past studies [9,59,60] that the amount of residual soil NO_3^- is among the most governing factors of N leaching in addition to current fertilizer rate. A year-round use of high amount of N fertilizer for vegetable production favors continuous accumulation of mineral residual N (NO_3^- and NH_4^+) in the soil profile which is amenable to leaching risk. Hence, higher amount of N leaching is probably more experienced from onion production system of Dugda, ATJK and Zeway Dugda districts of the CRV. The residual soil mineral N (sum of NO_3^--N and NH_4^+-N) content after onion harvest was shown to be high (776–828 kg ha^{-1}) in 0-20 cm soil depth [11]. Therefore, the actual amount of N loss in the leachates for the actual production area could be higher than quantified in here.

3.4 Nitrogen Uptake and Dry Matter Accumulation

Independent t-test showed no significant difference (P > .05) between applications of 1.00 CWR and 1.25 CWR on total N uptake and total dry matter (DM) accumulation (oven dry basis) at harvest (117 DAT) (Table 3). The 1.00 CWR is actually the ideal amount of water required by the crop for adequate metabolism to support the maximum growth and development provided that other plant growth conditions are suitable [61]. The extra amount of water (1.25 CWR) that could cause increased removal of N below plant root did not influence the total N uptake and total DM accumulation consistently as observed for the three sampling dates. Onion, being shallow rooted crop, is reported to be mainly sensitive to water deficiency [62] than to excess water.

On the other hand, the t-test showed significant difference (P<0.05) between different sub groups of N fertilizer application rates on total N uptake except between 92 and 184 kg N ha^{-1} sub group (Table 4). The amount of total N uptake by the onion crop was high even under no N fertilizer application (about 89.4 $\pm$1.47 kg ha^{-1}). This could be from soil organic matter mineralization and N added with irrigation water. Based on the irrigation water NO_3^- concentration (18.91 mg L^{-1}), about 20.12 to 29.89 kg N was added with the irrigation water used per hectare. The soil nitrate and ammonia was not quantified at the beginning of the experiment, but expected to be moderate in the research plot soils due to continuous use of urea for experiments. Better management of N fertilizer recommends compensating N application rate for residual soil mineral N and N to be obtained from soil organic matter mineralization and irrigation water [63]. Growers often apply high amount of N to ensure high yield of onion bulb. The excess amount of N exceeding the crop uptake will be retained in the soil profile for next crop uptake and leaching loss.

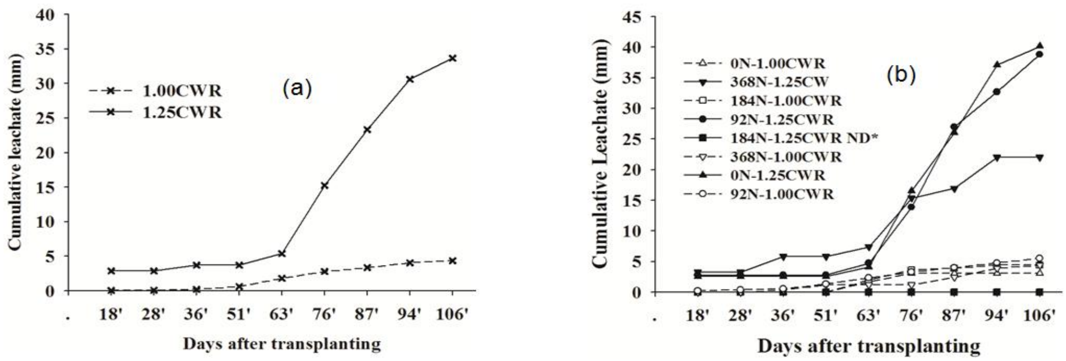

Fig. 2. Cumulative drainage due to irrigation water levels (a), and combination of irrigation water levels and urea fertilizer rates (b)

ND = no leachate was obtained from a plot that received 184N_125%CWR*

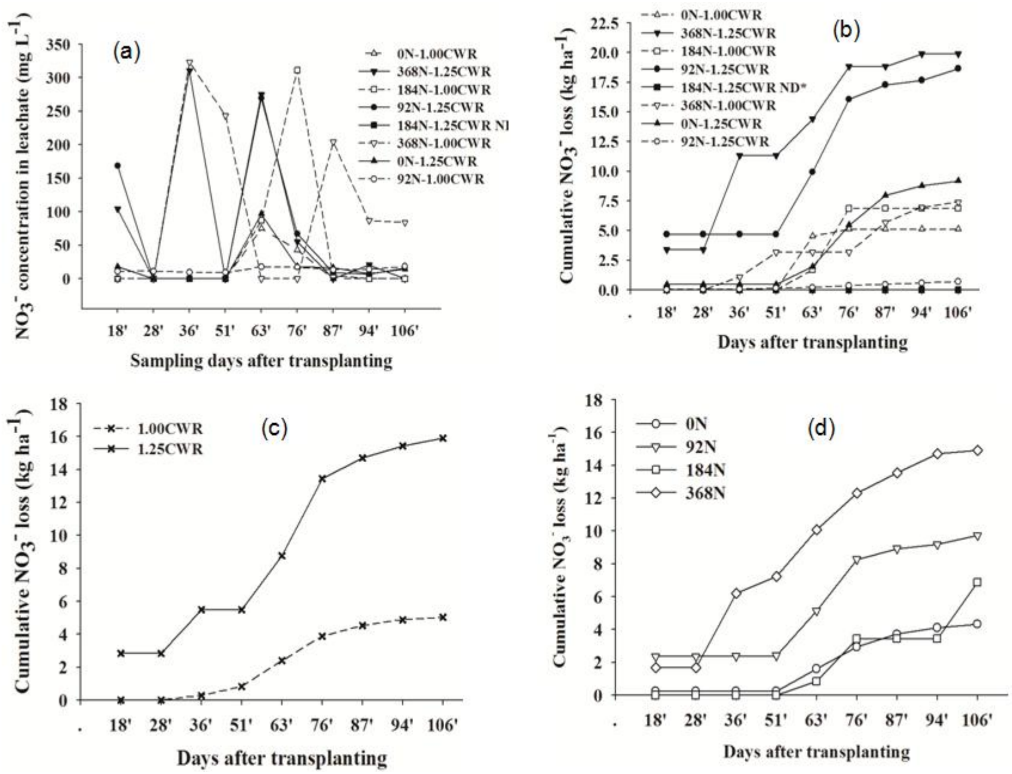

Fig. 3. Nitrate concentration in leachate (a), cumulative NO_3^- leaching losses due to: treatments (b), irrigation water levels (c), and N application rates (d). ND* not determined because no leachate was obtained from a plot that received 184N-1.25 CWR

Table 2. Cumulative irrigation water and leachate (mm) for the treatments assigned to lysimeter plots

Description	Treatments								Average ±SE	
	0N-1.00 CWR	92N-1.00 CWR	184-1.00 CWR	368N-1.00 CWR	0N-1.25 CWR	92N-1.25 CWR	184N-1.25 CWR	368N-1.25 CWR	1.00 CWR	1.25 CWR
Irrigation water	464.5	492.2	458.2	393.1	583.3	686.1	495.3	518.4	452.0±21.0	570.8 ± 42.7
Leached water flux	3.1	5.5	4.4	4.4	39.1	38.8	Trace[1]	21.0	4.4 ± 0.5	33.0 ± 5.19
Water leached (%)[2]	0.66	1.12	0.97	1.12	6.70	5.66	NA	4.04	1.0 ± 0.1	5.5 ± 0.67

[1]unfortunately no leachate was obtained from this plot, [2] total leachate collected divided by total irrigation water applied multiplied by 100
NA= not applicable, SE= standard error

Table 3. Nitrogen uptake and DM accumulation as affected by irrigation water levels pooled over different N fertilizer rates

Plant part	Sampling date	N accumulation (kg ha^{-1}) ±SE		% change over the 1.00 CWR	DM accumulation (Mg ha^{-1}) ±SE		% change over the 1.00 CWR
		1.00 CWR	1.25 CWR		1.00 CWR	1.25 CWR	
Leaf and stem	39 DAT	59.67±6.26	54.21±4.77	-9.15	2.15±0.07	2.11±0.13	-1.86
	85 DAT	49.85±0.69	53.07±1.87	6.46	2.66±0.13	2.61±0.15	-1.88
	117 DAT	15.62±2.94	18.58±3.29	18.95	2.36±0.10	2.33±0.18	-1.27
Bulb	39 DAT	11.46±1.20	14.24±3.31	24.26	0.61±0.03	0.72±0.13	18.03
	85 DAT	35.00±4.42	38.96±3.95	11.31	2.65±0.23	2.57±0.17	-3.02
	117 DAT	89.51±3.51	85.32±2.73	-4.68	5.14±0.17	5.07±0.21	-1.36
Total[1]	39 DAT	71.12±7.43	68.45±7.89	-3.75	2.77±0.09	2.83±0.25	2.17
	85 DAT	84.85±3.88	92.03±4.87	8.46	5.31±0.35	5.17±0.29	-2.64
	117 DAT	105.13±5.58	103.91±5.79	-1.16	7.51±0.23	7.39±0.31	-1.60
HI		-	-	-	0.69±0.01	0.69±0.02	-

[1] Total is sum of N in leaf and stem, and in bulb at indicated days after transplanting; HI= harvest index; SE= standard error

Table 4. Nitrogen uptake and DM accumulation as affected by N fertilizer rates averaged over different irrigation water levels

Plant part	Sampling date	N accumulation in DM (kg ha^{-1}) $\pm$SE			
		0N	**92N**	**184N**	**368N**
Leaf and stem	39 DAT	42.2 ±1.11	59.1 ±1.72	57.7 ±3.04	68.74 ±5.05
	85 DAT	49.9 ±0.19	50.6 ±0.69	52.1 ±4.17	53.16 ±3.15
	117 DAT	11.3 ±0.56	15.0 ±3.05	16.5 ±2.13	25.56 ±1.30
Bulb	39 DAT	7.6 ±0.38	12.5 ±0.07	13.0 ±1.06	18.3 ±4.81
	85 DAT	28.6 ±2.50	36.2 ±6.54	39.7 ±5.89	43.4 ±4.76
	117 DAT	78.1 ±0.91	90.1 ±2.25	90.3 ±2.77	91.2 ±2.45
Total[1]	39 DAT	49.8 ±1.49	71.6 ±1.64	70.7 ±1.97	87.1 ±0.23
	85 DAT	78.5 ±2.31	86.8 ±5.85	91.9 ±1.71	96.55 ±7.91
	117 DAT	89.4 ±1.47	105.1 ±0.81	106.8 ±0.63	116.8 ±1.16
		DM accumulation (Mg ha^{-1}) $\pm$SE			
		0N	**92N**	**184N**	**368N**
Leaf and stem	39 DAT	1.92 ±0.04	2.04 ±0.09	2.19 ±0.02	2.38 ±0.07
	85 DAT	2.39 ±0.03	2.53 ±0.20	2.69 ±0.18	2.92 ±0.06
	117 DAT	2.12 ±0.07	2.26 ±0.03	2.24 ±0.07	2.76 ±0.10
Bulb	39 DAT	0.55 ±0.01	0.60 ±0.09	0.68 ±0.06	0.84 ±0.24
	85 DAT	2.34 ±0.08	2.44 ±0.11	2.47 ±0.00	3.20 ±0.12
	117 DAT	4.61 ±0.08	5.10 ±0.03	5.52 ±0.00	5.20 ±0.04
Total[1]	39 DAT	2.47 ±0.04	2.64 ±0.18	2.87 ±0.04	3.22 ±0.31
	85 DAT	4.72 ±0.06	4.97 ±0.30	5.16 ±0.18	6.12 ±0.18
	117 DAT	6.73 ±0.15	7.35 ±0.06	7.76 ±0.07	7.96 ±0.06
Harvest index		0.68±0.00	0.69±0.00	0.71±0.01	0.65±0.01

[1]Total is sum for leaf, stem and bulb, SE= standard error

Total DM accumulation at harvest was superior (at $P < 0.05$) for 184 and 368 kg N ha^{-1} rates compared to no N application. The difference was further significant between application of 92 and 368 kg N ha^{-1}. Other rates such as 184 and 368 kg N ha^{-1}, which were significantly different for N uptake, were not different for the total DM accumulation at harvest indicating the decreasing N use efficiency with increasing N rates. The N uptake and DM accumulation in bulb increased continuously until harvest while that of leaf and pseudo-stem started decreasing after 85 DAT. This shows the translocation of nutrients from the leaf to the sink organ [51].

Harvest index response to application of 184 kg N ha^{-1} was relatively high (0.71) as compared to its response to other application rates. The harvest index values were in consent with the finding of Hedge [50] for *Allium cepa*. The lowest harvest index was recorded for higher N and irrigation water application (368N-1.25 CWR) that indicates extended and higher above ground pseudo stem and leaf growth without proportionally contributing to bulb dry weight.

3.5 Nitrogen Balance

N balance showed considerable accumulation of N in the soil profile in response to N fertilizer application rates (Table 5). Without considering internal organic matter mineralization release of soil N, about 48.5 to 69.4% of the applied higher rates of N fertilizer were accumulated in the soil profile per production season (Table 5).

In line with the results of this study, lower N recoveries from soil applied N fertilizers in vegetable crops including onion was reported [8,9]. Another similar study depicted that about 98% of residual soil N after harvest of grain wheat was explained by applied N fertilizer [9]. The result implies that there will be large amount of N, far beyond the level of N withdrawal by the onion crop, accumulation in the soil profile. This will be liable to loss to ground water unless its major part is accounted for in the next season's crop uptake. The irrigation water source used in this experiment was Awash River containing about 18.9 mg L^{-1} NO_3^-. Lake Zeway, major source of irrigation water in the CRV of Ethiopia, is comparable to this river in its NO_3^- concentration. Nitrogen from irrigation water accounting for significant proportion of plant nutrient was also reported in similar study [1]. Hence, it is important for farmers to compensate for the amount of N added with irrigation water in their N fertilizer use under irrigated conditions.

Table 5. Soil N balance for evaluated treatments at harvest

Treatments	In flows (kg ha^{-1})		Out flows (kg ha^{-1})			Soil N balance[1] (kg ha^{-1})	Soil N balance[2] (kg ha^{-1})
	N from fertilizer	N from irrigation water	N extracted by plant	N leached	Ammonia volatilized*		
0N-1.00 CWR	0.0	23.78	90.87	0.42	0.00	-67.51	0.00
92N-1.00 CWR	92.0	25.19	104.34	0.18	4.60	+8.07	+75.58
184N-1.00 CWR	184.0	23.45	107.41	1.55	9.20	+89.30	+156.81
368N-1.00 CWR	368.0	20.12	117.93	1.67	18.40	+250.12	+317.63
0N-1.25 CWR	0.0	29.86	87.93	1.54	0.00	-59.61	0.00
92N-1.25 CWR	92.0	35.12	105.95	4.21	4.60	+12.36	+71.97
184N-1.25 CWR	184.0	25.35	106.14	NA	9.20	NA	NA
368N-1.25 CWR	368.0	26.53	115.62	5.07	18.40	+255.45	+315.05

** Ammonia volatilization estimated to be about 5% of the applied N from fertilizer*

[1] soil organic matter mineralization was not considered, [2] soil organic matter mineralization was considered

Table 6. Onion bulb yield (Mg ha^{-1}), yield advantages, storage weight loss and HI as affected by irrigation water levels and N fertilizer rates

Treatments	Marketable bulb yield	Unmarketable bulb yield	Total bulb yield	Yield advantage[1] over the local control[2]	Weight loss[1] during 45 days of storage
0N-1.00 CWR	25.38	0.68	26.06	-1.44	7.29
92N-1.00 CWR	25.75	0.46	26.21	-	8.45
184N-1.00 CWR	33.22	0.68	33.90	29.01	15.57
368N-1.00 CWR	31.88	0.50	32.38	23.81	20.15
0N-1.25 CWR	24.79	1.15	25.94	-3.73	14.28
92N-1.25 CWR	25.07	1.19	26.26	-2.64	11.05
184N-1.25 CWR	31.74	1.45	33.19	23.26	29.15
368N-1.25 CWR	31.57	1.77	33.34	22.60	25.01

[1]percent yield loss during storage period and percent yield advantages were computed from the marketable bulb yield, [2]the 92N-1.00 CWR was existing research recommendation practice considered as local control

Multiple and often interrelated factors make prediction of volatilization variable and difficult under field conditions [64,65]. The study areas' high soil pH (Table 1) and soil temperature (25.4 to 26.7ºC) for 0 to 50 cm soil depth from the nearby MARC weather station, and the increasing rate of urea fertilizer use [10,11] favor ammonia volatilization. On the other hand, the commonly used practice of split application (at trans/planting and top dressing) of N fertilizer, mostly incorporated to soil or irrigation after fertilizer application in the study area, contributes towards minimization of ammonia volatilization [45,46,66]. Other processes not considered in Equations 1 and 2, but can affect the dynamics of soil N balance could be considered as limitations to the N balance computed in this experiment. But, these were usually assumed quite small [39].

3.6 Yield Response, Nitrogen Use Efficiency, and Irrigation Water Productivity

Marketable bulb yield response to applications of 184 and 368 kg N ha^{-1} was significantly different (P< 0.05) compared to no application or to application of 92 kg N ha^{-1} (Table 6). However, the difference was not statistically significant (P ≥ 0.05) between application of 184 and 368 kg N ha^{-1} indicating that additional fertilizer use above 184 kg N ha^{-1} is not only unnecessary cost of production but it also accumulates N in the soil liable to leaching loss. The marketable yield advantages due to applications of additional fertilizer above the local control (92 kg N ha^{-1} with 1.00 CWR) were generally between 22.60 and 29.01% (Table 6). Studies in different countries indicated that N fertilizer rates up to 200 kg N ha^{-1} can result in optimum onion bulb yield [51,67,68]. Furthermore, no significantly different marketable yield was found (P ≥ 0.05) between applications of the two irrigation water levels; 1.00 CWR and 1.25 CWR. From these, it can be deduced that farmers using high rates can reduce their inputs (fertilizer and irrigation water) and consequently N leaching (that otherwise contributes to environmental pollution) without significantly reducing yield. Bulb yield response to N fertilizer rates was moderate and the yield under no N fertilizer application was also fair. This was probably due to the status of experimental soil which was moderate in its organic matter to supply N on mineralization and the N obtained from irrigation water.

The total bulb yield significantly and positively correlated with Leaf Area Index (LAI) both at 63 DAT (r= 0.89) and 85 DAT (r=0.79) (data not presented here). Higher LAI suggest relatively higher interception of the total incident light by leaves that contribute to onion bulb yield [69]. This positive correlation between yield and LAI was in conformity to expectation.

Storage loss due to physiological weight loss, rotting, and sprouting were depicted during the 45 days of onion bulb storage. The storage loss remained minimum for treatments combing lower fertilizer rates and 1.00 CWR irrigation water levels (Table 6). Treatments with higher fertilizer rates (184 and 368 kg ha^{-1}) were found to be the most susceptible to storage loss in general. Rotting was the major cause of storage loss in bulbs from plots that received 368 kg N ha^{-1}. Similar to the current finding, previous studies reported that higher nitrogen fertilizer rates, and lower (stressed) or excess irrigation water could adversely affect storability of onion bulbs [70]. This is attributable to the fact that initially bulbs had more moisture to loose when grown at 1.25 CWR and tend to rot under high N application [70]. Other studies that showed adverse effect of lower irrigation levels (water stressed condition) on the conservation of stored onion bulbs [71,72] recommended to avoid excess and lower irrigation levels both for yield advantage and bulb storability.

Nitrogen recovery decreased with increasing N application rate. The higher recoveries, 14.64 and 19.59%, were recorded in plots that received 92 kg N ha^{-1} with 1.00 CWR and 1.25 CWR, respectively (Table 7). A study result by Halvorson et al. [8] also reported lower recovery of N (average of 15%) in onion production under furrow irrigation in Colorado, USA. Other study, on the other hand, showed recoveries up to 40% [73] under well managed irrigation. The shallow and sparse root system of onion crop under furrow irrigation is probably among the reasons for poor capacity to exploit the applied nitrogen fertilizer. This indicates that much of the applied fertilizer N remained in the soil and will be liable to various types of losses such as leaching and gaseous losses [1–3,9,45].

The use efficiency of nitrogen taken up by onion crop (kg kg^{-1}) was relatively high for application of 184 kg N ha^{-1} at both irrigation water application levels (Table 7). The lower use efficiency of nitrogen at higher N application was probably due to luxury up take of the nutrient. The decreasing use efficiency with increasing application of N fertilizer is in harmony with other

Table 7. NREC, NuptUE and IWP of the applied fertilizer rates and irrigation water levels

Fertilizer rate	NREC (%)			NuptUE (kg kg^{-1})[1]			IWP (kg m^{-3})[2]		
	1.00 CWR	1.25 CWR	Mean	1.00 CWR	1.25 CWR	Mean	1.00 CWR	1.25 CWR	Mean
0N	-	-	-	286.71	294.98	290.84	5.61	4.45	5.03
92N	14.64	19.59	17.11	251.15	247.87	249.51	5.32	3.83	4.58
184N	8.99	9.90	9.44	315.60	312.73	314.17	7.40	6.70	7.05
368N	7.35	7.52	7.44	274.59	288.36	281.48	8.24	6.43	7.33
Mean	10.33	12.34		282.01	285.98		6.64	5.35	6.00

[1]NuptUE=Nitrogen taken up Use Efficiency, [2]IWP = Irrigation Water Productivity calculations were based on total fresh onion bulb yield

study results [1,73]. However, the reason why this use efficiency was exceptionally low for 92 kg N ha^{-1} application rate even when compared to no fertilizer application was unclear. Indeed, considering plant demand and avoiding over fertilization is recommended as primary means to match a high use efficiency of fertilizer-N with limited environmental risks from nitrate leaching [9,53].

Irrigation water productivity (IWP) showed improvement with increasing rate of N fertilizer (Table 7). Water and nutrient supply to plants are closely interacting factors influencing plant growth and yield. Previous works in this regard showed that application of fertilizers enhances water productivity by improving the water use efficiency [74,75]. The increased irrigation water level above 1.00 CWR resulted in decreased IWP as it favors extended above ground vegetative growth that did not proportionally contribute to bulb yield [51,52]. Hence, farmers' irrigation practice beyond crop water requirement is contributing to drainage loss that removes NO_3^- below root depth without improving IWP.

4. CONCLUSION AND RECOMMENDATION

In this study, drainage lysimeter planted with onion (*Allium cepa* L.) was used to quantify nitrate leaching under farmers' fertilizer and irrigation water use practices. This was to support sustainable use of nutrient and irrigation water in the production system.

Nitrate leaching quantified for the season was low. Indeed, the result implies that vegetable producing farmers' higher fertilizer rates (368 kg ha^{-1}) and irrigation water (1.25 CWR) use in the study area has important contribution to some level of nitrate leaching loss without significantly contributing to the total DM accumulation and marketable bulb yield. The amount of N inflow to the farm by farmers practicing high rate of N fertilizer in combination with N from irrigation water and soil organic matter mineralization was far beyond the level of N withdrawal by the onion crop. The practice in the study area is hence, accumulating N in the soil profile, making it liable to leaching and gaseous losses unless well captured by the next season's crop. The practice has further adverse effect on storability of bulb and implications to market opportunity. Irrigating at 1.00 CWR and N fertilizer not exceeding about 184 kg N ha^{-1} could be considered as provisional recommendation to reduce the problem with no significant yield reduction. Nevertheless, the problem requires further study on various soils of the study area comprising various vegetable production and farmers' complete crop rotation practice.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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