Effect of Irrigation Water and Organic Fertilizer on Reducing Nitrate Accumulation and Boosting Lettuce Productivity

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Abstract

Accumulation of high level of nitrate (NO_3^-) in leaves is a serious issue for vegetable crops like lettuce (*Lactuca sativa* L.). Therefore, this study aimed to limit NO_3^- level by adjusting the balance between fertilization and irrigation program in lettuce. In a strip plot design with three replicates, lettuce plants were grown under four fertilizer treatments and three irrigation regimes. Three organic fertilizers (biochar, compost and vermicompost), in addition to mineral fertilizer, were used. The irrigation regimes were 60, 80 and 100% of crop evapotranspiration, ETc (ETc60, ETc80, and ETc100). Nitrogen (N), phosphorus (P) potassium (K) and organic matter (OM) in soil as well as yield, N, P, K and NO_3^- of lettuce were estimated. Findings showed that vermicompost or biochar (with any irrigation regime) as well as compost with irrigation by ETc60 were the effective combinations for increasing K content in soil after harvest. Under irrigation by ETc80 or ETc100, vermicompost or biochar were the efficient treatments for increasing lettuce yield equaling the farmer common practice (ETc100 x mineral fertilizer). Under irrigation by ETc60, mineral fertilizer or vermicompost showed the highest lettuce leaf content of K. Moreover, ETc60 or ETc80 x mineral fertilizer recorded the maximum NO_3^- content of lettuce leaves. The accumulation of nitrate in lettuce leaves owing to mineral fertilizer reached about 1.24 times than that of organic fertilizers. Compost x ETc80 or ETc100 showed the minimal NO_3^- -N accumulation, hence, high relative reductions in NO_3^- -N accumulation as compared to the common practice (ETc100 x mineral fertilizer) were observed. In conclusion, irrigation by 80% instead of 100% of crop evapotranspiration of organically fertilized lettuce (especially with vermicompost) could be adopted since such practice recorded high lettuce productivity with low NO_3^- content.

Keywords Irrigation pattern · Leaf nitrate content · Lettuce yield · Nutritional value · Slow-release fertilizer · Soil water content

1 Introduction

Lettuce (*Lactuca sativa* L.) is a leafy vegetable crop regarded as one of the major greenhouse-grown plants, owing to its high productivity and economic value (Křístková et al.

2008). Lettuce has been counted as a significant functional food because of containing vitamins and minerals (Kim et al. 2016). However, high amount of nitrate (NO_3^-) could accumulate in leaves of lettuce (Kmecl et al. 2017; Zandvakili et al. 2019). The danger of NO_3^- is that it turns into nitrites (NO_2^- , toxic compounds) in the gastrointestinal tract of human body (about 5–10% of absorbed NO_3^-), causing dangerous diseases (Pinto et al. 2015; Salehzadeh et al. 2020). Thus, the attempts to reduce NO_3^- in lettuce leaves should be adopted continuously.

The nitrate concentration in vegetable plants varied according to various factors, e.g., nitrogen fertilizer management, light intensity, water stress and soil pH (Boroujerdnia et al. 2007; Pavlou et al. 2007). Lettuce is highly responsive crop to mineral fertilizers. In this regard, progressive increases in plant height, number of leaves per plant,

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fresh and dry weights, and yield of lettuce were recorded with increasing nitrogen rate (Cercioglu et al. 2012; Tsia-karas et al. 2014). However, with immoderate application of nitrogen fertilizer, vegetables can accumulate high levels of nitrate. Upon being consumed by human, nitrate causes serious health hazards (Umar and Iqbal 2007). Increasing the accumulation of nitrate in lettuce leaves owing to applying mineral fertilizers has been reported (Hoque et al. 2010; Tabaglio et al. 2020). Because reducing nitrate content can add value to vegetable products (Santamaria 2006), organic fertilizers could introduce better solution toward this issue, since lettuce growth, yield and vitamin C content were higher in the organic production system than conventional systems (Caliskan et al. 2014). Since organic fertilizers provide steady supply of several nutrients and improve physical, chemical and biological properties of the soil, increases in lettuce growth and nutrients concentration and uptake were achieved (Moreira et al. 2014). Compost as an organic source of fertilizers is a valuable product that manipulates soil properties, via improving organic matter content, nutrient availability, aeration and water holding capacity and reducing soil bulk density (Mostafa et al. 2019). Moreover, the use of biochar for soil restoration and biofertilization has increasingly received interest as low-cost and eco-friendly amendment (Lone et al. 2015). Biochar caused a positive impact on soil stability by altering the size of aggregates and regulating soil water, actions that may promote plant growth (Obia et al. 2016). In addition, vermicompost as an organic fertilizer plays a role in enhancing soil fertility, increasing soil–water holding capacity and soil aggregates (Abul-Soud et al. 2014). It is rich in many nutrients such as N, P, K, Ca and Mg that are readily available to plant absorption (Hashem and Abd-Elrahman 2016).

Another significant aspect associated with lettuce cultivation is irrigation. Irrigation levels not only affect the yield but also the uptake and accumulation of nitrates in crop plants (Saady et al. 2020; El-Metwally et al. 2022). Subjecting plant to excessive or deficit water leads to increasing nitrate accumulation (Schiattone et al. 2018). With excessive irrigation, nutrients are highly prone to leaching from the root zone (Maynard and Hochmuth, 2007). Also, irrigation water use efficiency decreased as the irrigation level increased (Bozkurt et al. 2009; El-Metwally et al. 2021). On the other site, Koyama et al. (2012) found that appropriate rhizosphere drought stress decreased the nitrate concentration by 18% without reducing the yield of lettuce. In this regard, photo-oxidation of plant pigment degradation is regarded as a norm event of oxidative stress resulting from the adverse impact of low water supply. Owing to severe water stress, chloroplast is the first sign to be injured, since it is the master site for production of reactive oxygen species (ROS) (Munné-Bosch and Peñuelas 2003). Also, water deficit promotes production of abscisic acid, which reduces

carbon dioxide influx and inhibits photosynthesis by stimulating stomata closure (Chaves et al. 2009; Makhlof et al. 2022). The paucity of intracellular CO₂ due to extended stomatal closure causes the cumulation of ROS and damages the photosynthetic system (Laxa et al. 2019). Additionally, being water deficiency causes turgor loss, reductions in growth rate, foliar expansion, stomatal opening and photosynthesis process were recorded (Bhargava and Sawant 2013). However, the response of lettuce and accumulated nitrate to low water supply at farm level may differ.

The hypothesis of the current work was that the integrated effect of organic fertilizers and watering less than full irrigation could improve soil properties and yield of lettuce with reducing nitrate concentration in leaves. Therefore, the study aimed to investigate the possible changes in soil nutrient status and yield and quality of lettuce resulting from different combinations of organic fertilizers and irrigation regimes.

2 Materials and Methods

2.1 The Experimental Site

Under open field conditions, a 2-year experiment was carried out during 2018 and 2019 in winter seasons at Dokki Protected Cultivation Experimental Site, Central Laboratory for Agricultural Climate, Agricultural Research Center, Giza Governorate, Egypt. The meteorological data of the experimental site during the two studied seasons are shown in Table 1. The experimental soil was clay as well as its physical (Klute 1986) and chemical (Page et al. 1982) properties were estimated as shown in Table 2.

2.2 Plant Material and Design

Seeds of iceberg lettuce (*Lactuca sativa* var. *capitata* cv. Chianti) were sown on February 25th and 24th in 2018 and 2019 seasons, respectively, in polystyrene trays. After four weeks from sowing, lettuce seedlings were transplanted in open field, 30 cm apart on both sides of the ridge. In a strip plots design with three replicates, four fertilizer treatments (three organic fertilizers, i.e., biochar, compost and vermicompost in addition to mineral fertilizers) as well as three irrigation regimes (60, 80 and 100% of crop evapotranspiration, ET_c) were tested. The whole experimental plot size was 3.8 m × 3.6 m with a net area of 10.5 m², involving five ridges, 3.5 m length and 0.6 m width (Fig. 1).

2.3 Organic Fertilizers Preparation

Biochar According to Yu et al. (2013), the biochar was produced by heating air-dried tree branch clippings using slow pyrolysis for two hours (about 360–420 °C) in a pilot-scale

Table 1 Meteorological data at Dokki Protected Cultivation Experimental Site, Egypt, during lettuce growing season of 2018 and 2019

Week	Mean temperature (°C)		Solar radiation (MJ m ⁻² day ⁻¹)		Relative humidity (%)		Wind speed (m s ⁻¹)	
	2018	2019	2018	2019	2018	2019	2018	2019
1	14.1±0.1	11.0±0.2	20.1±0.3	14.3±0.1	52.5±0.6	50.2±0.8	3.17±0.18	2.70±0.12
2	13.7±0.1	11.0±0.1	16.5±0.3	12.2±0.1	51.0±0.7	49.0±0.7	3.49±0.15	2.36±0.13
3	15.7±0.2	11.1±0.1	20.3±0.2	13.3±0.2	47.3±0.6	45.9±0.5	2.49±0.18	2.44±0.15
4	16.4±0.1	12.1±0.2	21.3±0.4	15.8±0.3	46.5±0.4	43.7±0.6	3.23±0.14	1.98±0.12
5	13.9±0.2	13.4±0.3	23.0±0.2	18.8±0.3	48.6±0.6	48.1±0.4	3.31±0.19	2.43±0.11
6	18.1±0.3	14.6±0.4	25.2±0.4	15.7±0.2	36.2±0.5	34.1±0.8	3.34±0.20	3.40±0.17
7	20.5±0.3	17.2±0.2	22.8±0.2	18.2±0.4	31.5±0.3	32.4±0.9	3.10±0.13	3.00±0.19
8	18.9±0.2	16.8±0.3	26.0±0.3	21.6±0.2	34.6±0.5	35.1±0.4	2.75±0.11	2.74±0.16

The first week began on 25 and 24 March during 2018 and 2019 seasons, respectively. The meteorological data were obtained from Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt. Values are the mean of three replicates ± standard errors

Table 2 Physico-chemical properties and water status of soil at Dokki Protected Cultivation Experimental Site, Egypt

Parameter	Unit	Value
Mechanical analysis		
Sand	% by weight	16.9±0.1
Silt	% by weight	30.8±0.2
Clay	% by weight	52.3±0.4
Bulk density	g cm ⁻³	1.35±0.08
Chemical analysis		
pH (1:2.5)	–	7.64±0.06
Electrical conductivity (EC)	dS m ⁻¹	2.69±0.02
Organic matter	g kg ⁻¹	8.06±0.10
Available nitrogen	mg kg ⁻¹	37.3±0.2
Available phosphorus	mg kg ⁻¹	2.01±0.02
Available potassium	mg kg ⁻¹	148.0±2.2
Calcium cations (Ca ²⁺)	meq L ⁻¹	5.45±0.02
Magnesium cations (Mg ²⁺)	meq L ⁻¹	3.87±0.03
Sodium cations (Na ⁺)	meq L ⁻¹	11.60±1.05
Potassium cations (K ⁺)	meq L ⁻¹	5.98±0.11
Chloride anions (Cl ⁻)	meq L ⁻¹	12.9±0.52
Bicarbonate anions (HCO ₃ ⁻)	meq L ⁻¹	7.05±0.10
Sulfate anions (SO ₄ ²⁻)	meq L ⁻¹	6.95±0.1
Calcium carbonate (CaCO ₃)	g kg ⁻¹	56.1±0.6
Water status		
Saturation percentage	% by volume	87.9±2.0
Field capacity	% by volume	62.1±1.4
Wilting point	% by volume	27.8±1.6

Carbonate anions (CO₃²⁻) were not detected. Values are the mean of three replicates ± standard errors

electric pyrolyzer. After cooling, the biochar was passed through a 2-mm sieve.

Compost The compost was prepared using the Indore method (Inckel et al. 2005). Briefly, the alternative layers of organic mixtures (80% plant residues, i.e., cucumber, eggplant and tomato + 20% cattle manure) were used to make the compost pile (1.25×2.50×0.75 m³ in size). A plastic sheet was used to cover the ground before making the pile to prevent nutrients solution leakage during watering the plant residues. Also, the pile was covered by clear plastic sheet to keep up the water content and to help in the decomposition process by increasing temperature. This process took approximately 4 months.

Vermicompost Processing involves collection of organic wastes. Pre-composting of organic waste (Nair et al. 2006; Frederickson et al. 2007) for ten days was done by mixing the organic material with cattle manure. This process partially digests the material and avoids the thermophilic stage. A layer of 15–20 cm of shredded newspaper kept as bedding material at the bottom of the bed. Beds of partially decomposed material of size 6×2×2 feet were made. Earthworm (330–350 worms per m³ of bed volume; worm diameter 0.5–5 mm and worm length 10–120 mm) were released in the upper layer of the bed. Water was sprinkled immediately after the release of worms. Every two days, beds were kept moist by sprinkling of water and turned for maintaining aeration.

Some chemical contents of biochar, compost and vermicompost are tabled (Table 3). The organic fertilizers were incorporated manually into the soil at the rate of 24 tons ha⁻¹ during land preparation and before lettuce transplanting by one week. Regarding the mineral fertilizers (control treatment), the recommended NPK fertilizers were applied. Herein, ordinary superphosphate was added during land

Fig. 1 Layout of the experiment with distribution of irrigation and fertilizer treatments. ETc60, ETc80 and ETc100 are irrigation by 60, 80 and 100% of crop evapotranspiration, respectively

preparation at a rate of 240 kg ha⁻¹. Ammonium sulfate [(NH₄)₂SO₄] and potassium sulfate (K₂SO₄) were added,

360 kg ha⁻¹, for each, in two batches, 15 and 30 days after transplanting (DAT).

Table 3 Some chemical contents of the tested organic fertilizers

Organic fertilizer	Nutrient concentration (mg kg ⁻¹)				C/N ratio
	N	P	K	C	
Biochar	14600 ± 100	5100 ± 200	13800 ± 700	187000 ± 1000	12.8 ± 0.02
Compost	17300 ± 200	5500 ± 300	13100 ± 300	172000 ± 1000	9.94 ± 0.06
Vermicompost	17700 ± 100	7600 ± 200	15600 ± 500	178000 ± 1000	10.1 ± 0.16

N: nitrogen, P: phosphorus, K: potassium, C: carbon. Values are the mean of three replicates ± standard errors

2.4 Water Requirements

Irrigation water treatments were implemented as a ratio of the crop evapotranspiration (ETc) including irrigation by 60% (ETc60), 80% (ETc80) and 100% (ETc100) of ETc. Based on the meteorological data (Table 1), the daily ETo was calculated using Eq. 1 (Allen et al. 1998) as follows:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where

ETo is reference evapotranspiration (mm day⁻¹), Δ is the slope of the saturation vapor pressure curve at air temperature (kPa °C⁻¹), R_n is net radiation at the crop surface (MJ m⁻² day⁻¹), G is soil heat flux density (MJ m⁻² day⁻¹), T is mean daily air temperature at 2 m height (°C), U₂ is wind speed at 2 m height (m s⁻¹), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), e_s - e_a is saturation vapor pressure deficit (kPa), and γ is psychrometric constant (kPa °C⁻¹).

Using Eq. (2), the crop evapotranspiration (ETc) was measured. Then, the volume of irrigation water applied to each treatment during the irrigation event was determined by using Eq. 3 (Doorenbos and Pruitt 1984; Keller and Bliesner 1990) as follows:

$$ETc = ETo \times Kc \quad (2)$$

where

ETc is crop evapotranspiration (mm day⁻¹), ETo is reference evapotranspiration (mm day⁻¹), and Kc is the crop coefficient as described by Allen et al. (1998).

$$IWA = \frac{A \times ETc \times Ii \times Kr}{Ea \times 1000 \times (1 - LR)} \quad (3)$$

where

IWA is the irrigation water applied (m³), A is the plot area (m²), ETc is the crop water requirements (mm day⁻¹), Ii is the irrigation intervals (day), Kr covering factor, Ea is the application efficiency (%) (Ea = 85), and LR is the leaching requirements (m³).

Accordingly, the gross seasonal irrigation water amounts based on irrigation treatments were about 2596,

3461 and 4327 m³ ha⁻¹ in 2018 season and 2486, 3314 and 4142 m³ ha⁻¹ in 2019 season with ETc60, ETc80 and ETc100, respectively.

Drip irrigation system was set up with 30.0-cm dripper spacing, and manufacturing dripper discharge 4.0 L hr⁻¹, at operating pressure of 1.0 bar. Flow meter was installed for each irrigation level treatment; borders of two meters were left between different irrigation strips. Lettuce plants were irrigated every 2 days interval by different amounts of irrigation water applied according to the irrigation treatment.

2.5 Assessments

After lettuce harvest, soil samples were collected at the 0–15 cm depth. The collected samples were air-dried, crushed and sieved through a 2-mm sieve and prepared to determine chemically available concentrations of nitrogen (N), phosphorus (P) and potassium (K) as well as organic matter (OM) content in soil (Page et al. 1982). Moreover, samples of three plants of each experimental plot were taken at 55 days from transplanting date, to estimate head weight (lettuce yield ha⁻¹). For mineral analysis of leaves, three plant samples of each plot were dried at 65 °C in an air-forced oven for 48 h. Dried leaves were digested by a mixture of H₂SO₄/H₂O₂ according to the method described by Chapman and Pratt (1961). Chemically available N in soil, and total N in plant were determined by micro-Kjeldahl method using 5% boric acid and 40% NaOH as described by Chapman and Pratt (1961). Nitrate was determined in the presence of Devarda's alloy and complete the same steps by micro-Kjeldahl method as described by Chapman and Pratt (1961). Phosphorus concentration was determined by ascorbic acid method using spectrophotometer according to Watanabe and Olsen (1965). Potassium concentration was determined using flame photometer as described by Chapman and Pratt (1961).

2.6 Statistical Analysis

Since the outputs proved that the homogeneity and normality of the data are satisfied for running analysis of variance

(ANOVA), combined data of the two seasons were subjected to ANOVA according to Casella (2008), using Costat software program, Version 6.303, 2004. At $p \leq 0.05$ level of probability, Duncan's multiple range test was used for distinguishing among the treatment means.

3 Results

3.1 Soil Analysis

Despite nutrients and OM of soil decreased with increasing water amount, the differences among irrigation treatments were not significant, except K content (Table 4). Irrigation by ETc60 evenly with ETc80 recorded the maximum K value.

Vermicompost was similar to biochar in increasing N and K soil content (Table 4). Moreover, P and OM showed the highest values with vermicompost, biochar or compost. On the contrary, mineral fertilizer treatment recorded the lowest N, P, K and OM contents.

Organic fertilizer resources (vermicompost, biochar or compost), under all irrigation regimes, were similar for

recording the maximum increases in N, P and OM. Vermicompost and biochar (with any irrigation regime) as well as compost with irrigation by ETc60 were the effective combinations for increasing K content in soil (Table 4). In general, mineral fertilizer treatment caused higher reductions in N, P, K and OM contents under irrigation by ETc100, comparing to organic fertilizer treatments.

3.2 Lettuce Yield and Plant Analysis

Irrigation by ETc80 or ETc100 recorded 53.3 and 48.1% increases in lettuce yield, respectively, compared to ETc60 (Table 5). However, ETc60 gave the maximum values of plant nutrients content (N, P, K and $\text{NO}_3\text{-N}$) and leveled ETc80 significantly in P and $\text{NO}_3\text{-N}$. Moreover, ETc80 was similar to ETc100 for recording low values of N and $\text{NO}_3\text{-N}$. The reduction % in $\text{NO}_3\text{-N}$ accumulation due to ETc100 and ETc80 was 16.0 and 7.4% compared to ETc60.

The significant main effect of fertilization treatments showed that vermicompost and biochar caused increase in lettuce yield like that of mineral fertilizer (Table 5). Mineral fertilizer recorded the highest values of N, K

Table 4 Influence of irrigation (I) and fertilization (F) on nitrogen (N), phosphorus (P), potassium (K) and organic matter (OM) of lettuce soil after harvest

Variable	ETc60	ETc80	ETc100	Mean
Available N (mg kg^{-1})				
Biochar	72.7 $\pm$ 6.8a	72.6 $\pm$ 3.9a	64.4 $\pm$ 3.6abc	69.9 $\pm$ 2.8AB
Compost	64.7 $\pm$ 3.8abc	63.9 $\pm$ 4.3abc	58.7 $\pm$ 5.3abc	62.4 $\pm$ 2.5B
Vermicompost	75.2 $\pm$ 3.7a	74.5 $\pm$ 4.7a	71.1 $\pm$ 5.4ab	73.6 $\pm$ 3.1A
Mineral fertilizer	55.3 $\pm$ 4.0abc	52.2 $\pm$ 5.1bc	49.4 $\pm$ 3.6c	52.3 $\pm$ 2.4C
Mean	67.0 $\pm$ 3.0A	65.8 $\pm$ 2.8A	60.9 $\pm$ 2.7A	
Available P (mg kg^{-1})				
Biochar	4.15 $\pm$ 0.44ab	3.86 $\pm$ 0.33ab	3.73 $\pm$ 0.30ab	3.91 $\pm$ 0.21A
Compost	3.89 $\pm$ 0.43ab	3.37 $\pm$ 0.21ab	3.25 $\pm$ 0.37abc	3.51 $\pm$ 0.20A
Vermicompost	4.14 $\pm$ 0.30ab	4.40 $\pm$ 0.48a	3.91 $\pm$ 0.26ab	4.15 $\pm$ 0.20A
Mineral fertilizer	3.07 $\pm$ 0.30bc	2.87 $\pm$ 0.34bc	2.14 $\pm$ 0.12c	2.69 $\pm$ 0.17B
Mean	3.81 $\pm$ 0.19A	3.63 $\pm$ 0.20A	3.25 $\pm$ 0.19A	
Available K (mg kg^{-1})				
Biochar	230.3 $\pm$ 13.9ab	212.0 $\pm$ 18.4abc	191.0 $\pm$ 26.3abc	211.1 $\pm$ 11.6AB
Compost	217.5 $\pm$ 25.4abc	159.0 $\pm$ 20.6 cd	173.6 $\pm$ 14.0bcd	183.3 $\pm$ 12.7BC
Vermicompost	244.4 $\pm$ 27.1a	234.3 $\pm$ 20.4ab	210.4 $\pm$ 13.3abc	229.7 $\pm$ 11.9A
Mineral fertilizer	169.6 $\pm$ 17.8bcd	155.7 $\pm$ 10.2 cd	120.4 $\pm$ 7.14d	148.6 $\pm$ 8.4C
Mean	215.4 $\pm$ 11.7A	190.3 $\pm$ 10.9AB	173.8 $\pm$ 10.4B	
OM (g kg^{-1})				
Biochar	12.26 $\pm$ 1.22a	11.75 $\pm$ 0.61a	10.94 $\pm$ 0.88a	11.65 $\pm$ 0.53A
Compost	12.31 $\pm$ 0.71a	10.82 $\pm$ 1.11a	10.27 $\pm$ 0.79ab	11.13 $\pm$ 0.52A
Vermicompost	12.60 $\pm$ 0.67a	12.26 $\pm$ 0.84a	11.17 $\pm$ 0.87a	12.01 $\pm$ 0.46A
Mineral fertilizer	8.09 $\pm$ 0.57bc	7.61 $\pm$ 0.33c	6.99 $\pm$ 0.78c	7.56 $\pm$ 0.33B
Mean	11.31 $\pm$ 0.55A	10.61 $\pm$ 0.52A	9.84 $\pm$ 0.52A	

ETc60, ETc80 and ETc100: irrigation at 60, 80 and 100% of crop evapotranspiration, respectively. Values are the mean of three replicates $\pm$ standard errors. Varied letters within columns or rows indicates that there are significant differences by Duncan's multiple range test at $p \leq 0.05$

Table 5 Influence of irrigation (I) and fertilization (F) on yield, nitrogen (N), phosphorus (P), potassium (K) and nitrate ($\text{NO}_3\text{-N}$) of lettuce heads

Variable	ETc60	ETc80	ETc100	Mean
Yield (t ha^{-1})				
Biochar	20.6 $\pm$ 1.9ef	35.5 $\pm$ 1.7ab	33.9 $\pm$ 2.5ab	30.0 $\pm$ 1.9A
Compost	19.5 $\pm$ 1.2f	27.8 $\pm$ 2.3 cd	24.0 $\pm$ 2.2def	23.8 $\pm$ 1.3B
Vermicompost	25.6 $\pm$ 2.0cde	37.1 $\pm$ 2.5a	34.7 $\pm$ 2.6ab	32.5 $\pm$ 1.7A
Mineral fertilizer	19.7 $\pm$ 1.0f	30.6 $\pm$ 2.3bc	34.1 $\pm$ 1.9ab	28.1 $\pm$ 1.8AB
Mean	21.4 $\pm$ 0.9B	32.8 $\pm$ 1.3A	31.7 $\pm$ 1.4A	
N (mg kg^{-1})				
Biochar	25612 $\pm$ 1272b	21252 $\pm$ 1358bcd	19901 $\pm$ 879d	22255 $\pm$ 874B
Compost	24358 $\pm$ 1082bc	20454 $\pm$ 869 cd	19703 $\pm$ 1244d	21505 $\pm$ 765B
Vermicompost	25095 $\pm$ 1648b	22448 $\pm$ 1094bcd	20459 $\pm$ 839 cd	22667 $\pm$ 815B
Mineral fertilizer	30461 $\pm$ 1026a	24752 $\pm$ 1628bc	21349 $\pm$ 790bcd	25520 $\pm$ 1120A
Mean	26381 $\pm$ 778A	22227 $\pm$ 464B	20353 $\pm$ 464B	
P (mg kg^{-1})				
Biochar	7482 $\pm$ 37abcd	6953 $\pm$ 37bcdef	5712 $\pm$ 57ef	6715 $\pm$ 30AB
Compost	7065 $\pm$ 32bcde	6411 $\pm$ 43def	5483 $\pm$ 41f	6319 $\pm$ 27B
Vermicompost	8261 $\pm$ 38ab	7174 $\pm$ 41bcde	6221 $\pm$ 46def	7218 $\pm$ 30AB
Mineral fertilizer	8661 $\pm$ 39a	8091 $\pm$ 45abc	6632 $\pm$ 72cdef	7794 $\pm$ 33A
Mean	7867 $\pm$ 21A	7157 $\pm$ 23A	6012 $\pm$ 28B	
K (mg kg^{-1})				
Biochar	16403 $\pm$ 692bc	13504 $\pm$ 664de	12009 $\pm$ 540e	13972 $\pm$ 560C
Compost	15002 $\pm$ 454 cd	12250 $\pm$ 640e	9898 $\pm$ 412f	12383 $\pm$ 577D
Vermicompost	18003 $\pm$ 679ab	15001 $\pm$ 990 cd	12505 $\pm$ 729e	15170 $\pm$ 700B
Mineral fertilizer	19252 $\pm$ 738a	16696 $\pm$ 811bc	12955 $\pm$ 365e	16301 $\pm$ 724A
Mean	17165 $\pm$ 452A	14363 $\pm$ 505B	11842 $\pm$ 347C	
$\text{NO}_3\text{-N}$ (mg kg^{-1})				
Biochar	724.0 $\pm$ 43.2 cd	701.9 $\pm$ 50.2cde	646.8 $\pm$ 32.9def	690.9 $\pm$ 24.4B
Compost	648.0 $\pm$ 30.0def	596.8 $\pm$ 38.0ef	531.5 $\pm$ 36.2f	592.1 $\pm$ 22.2C
Vermicompost	815.1 $\pm$ 47.0bc	757.5 $\pm$ 33.8bcd	697.9 $\pm$ 41.5cde	756.8 $\pm$ 25.1B
Mineral fertilizer	940.8 $\pm$ 62.1a	839.0 $\pm$ 44.8ab	751.6 $\pm$ 38.2bcd	843.8 $\pm$ 32.7A
Mean	782.0 $\pm$ 31.6A	723.8 $\pm$ 26.9AB	657.0 $\pm$ 24.3B	

ETc60, ETc80 and ETc100: irrigation at 60, 80 and 100% of crop evapotranspiration, respectively. Values are the mean of three replicates $\pm$ standard errors. Varied letters within columns or rows indicates that there are significant differences by Duncan's multiple range test at $p \leq 0.05$

and $\text{NO}_3\text{-N}$ and exceeded all organic fertilizer forms in this respect. Moreover, P values of vermicompost or biochar were similar to that of mineral fertilizer treatment. Accumulation of K and $\text{NO}_3\text{-N}$ in lettuce leaves was low with the use of compost. It should be noted that $\text{NO}_3\text{-N}$ accumulation in lettuce leaves was less with organic fertilizers application (Table 5). The accumulation rates of $\text{NO}_3\text{-N}$ owing to biochar, compost and vermicompost were 18.1, 29.8 and 10.3% lower than mineral fertilizer.

Vermicompost and biochar x ETc80 or ETc100 were the efficient treatments for boosting lettuce yield and equaled the mineral fertilizer x ETc100 treatment (Table 5). Irrigation by ETc60 x mineral fertilizer showed the highest values of N, P, K and $\text{NO}_3\text{-N}$, and leveled with ETc60 x vermicompost in P and K content as well as irrigation by ETc80 x mineral fertilizer in $\text{NO}_3\text{-N}$ content.

As shown in Table 5, the higher values of $\text{NO}_3\text{-N}$ accumulation were recorded with ETc60 x mineral fertilizer. While the accumulation rates of $\text{NO}_3\text{-N}$ were less with using the different organic fertilizers under different irrigation regimes (Table 5). In this regard, compost x ETc80 or ETc100 showed the minimal $\text{NO}_3\text{-N}$ accumulation, hence, high relative reductions in $\text{NO}_3\text{-N}$ accumulation as compared to the common practice (mineral fertilizer x ETc100) were observed (Fig. 2).

4 Discussion

Results of the current research showed that the combinations of irrigation pattern plus fertilizer type have a distinctive role for changing the nutrient balance in soil in favor of crop growth. Findings showed that available K in lettuce soil after harvest was the most affected element by irrigation

Fig. 2 Reduction % in nitrate accumulation in lettuce as affected by organic fertilizers under different irrigation regimes relative to the common practice (mineral fertilizer x ETc100). ETc60, ETc80 and ETc100: irrigation at 60, 80 and 100% of crop evapotranspiration, respectively. Values are the mean of three replicates $\pm$ standard errors. Bars with different letters are statistically significant at $p \leq 0.05$

treatments, since limited accumulation in K was obtained with high irrigation level (ETc100). This result might be due to increasing leaching process with water abundance. The higher the water depth, the larger the percolated amount of the K^+ ion (Mendes et al. 2016).

Organic fertilizers preserved nutrients and enhanced organic matter content in soil comparing to mineral ones. After harvesting of lettuce crop, soil analysis detected the loss of soil nutrients and limitation of OM with application of mineral fertilizer treatment compared to organic ones (Table 4). This event was more evident with increasing irrigation water amount, since mineral fertilizer treatment x ETc100 caused higher limitations in N, P, K and OM content. In this context, Hepperly et al. (2009) reported that the continuous application of chemical fertilizers led to depression in soil properties and crop yields by time. Under nutrient deficiency conditions, farmers add a large amount of mineral fertilizers to ensure high yields (Agostini et al. 2010). However, a large quantity of N might be leached into groundwater and increase the contamination of water.

In addition to overdone fertilization, overdone irrigation is another common agricultural habit needed to be concerned (Liang et al. 2014). Excessive irrigation combined with excessive fertilization could easily lead to nutrient leaching issues, and then groundwater pollution (Thompson et al. 2007; Shi et al. 2009). On the other hand, some organic fertilizers use can modify soil physicochemical

conditions owing to their richness of organic matter and nutrients (Bhattacharyya et al. 2007; Sun et al. 2015). Also, Rutkowska et al. (2014) stated that long-term application of organic fertilizers can alter soil characteristics (e.g., pH and microorganisms) and therefore lead to soil richness in available forms of macronutrients. Moreover, variation in nutrient concentrations in soil after harvesting lettuce due to various organic fertilizers (vermicompost, biochar or compost) could be attributed to the difference in degree and rate of mineralization processes in soil as well as their organic carbon content. In this situation, the changes in applied organic fertilizer and released N, K and Ca in soil are relating on the manure type and soil traits (Hernández et al. 2016). Furthermore, organic fertilizers have soil microbial content and activity higher than chemical fertilizers (El-Mogy et al. 2020). These findings might be linked with the amounts of organic carbon in various organic fertilizers (Chakraborty et al. 2011; Amalraj et al. 2013). Since organic manures, i.e., vermicomposts have minerals in available forms (Table 3), enhancement of soil quality and nutrient availability to the plants were achieved (Birkhofer et al. 2008; Yang et al. 2015).

Efficient water and fertilizer management have been increasingly adopted in crop production. With using moderate deficit irrigation (90% of evapotranspiration), a reduction of N fertilizer input did not suppress crop yield, but increased water and N fertilizer use efficiencies (Cabello

et al. 2009). In this respect, the inappropriate soil water supply (too much or too little water) not only affects soil biological activities and soil properties (Salem et al. 2021), but also affects crop growth and productivity (El-Bially et al. 2018; El-Metwally and Saady 2021). Since irrigation by ETc80 was similar to ETc100 and better than ETc60 for recording high lettuce yield (Table 5), this may refer to achieving a better soil nutrient balance under moderate irrigation (ETc80) in lettuce. With adequate soil water supply, high soil enzyme and microbial activities and oxygen conditions were obtained (Borowik and Wyszowska 2016). Unlike, lowering water supply by 40% (ETc60) of normal (ETc100) could negatively influence the properties of the soil. In keeping with this trend, Mubarak et al. (2021) have reported that irrigation by 60% of crop evapotranspiration showed reduction in organic matter and carbon and soil activity. Due to the importance of water in promoting soil enzymes produced by microorganisms, water deficiency caused adverse impact on biological activity of soil biota (Hueso et al. 2012) and disturbance in the balance of nutrients soil and plant (Kim et al. 2008; Saady and El-Metwally 2019). Undoubtedly, imbalance of elements in the soil will negatively affect the growth of the crop. In addition, drought had negative impacts on plant physiological and growth and eventually resulted in low economic yield (Saady et al. 2021). Therefore, remarkable reduction in lettuce yield was observed owing to deficit water, i.e., irrigation by 60% of crop evapotranspiration (Table 5). These findings are in harmony with those obtained by Zhou et al. (2014) who found that water stress lowered dry matter and photosynthetic efficiency in lettuce.

Concerning lettuce chemical composition, in general, higher values of nutrient content in lettuce were produced with low water supply (ETc60), especially N and K content (Table 5). Compared to high water supply, low water supply lowered the rate of N leaching from soil, since water or nutrient solution was kept around the roots in the upper soil zone for a longer period (Tafteh and Sepaskhah 2012). Increasing irrigation water amount during crop growth stages could increase the nutrient leachates owing to the dilution effect of water (Hashem et al. 2014; Hashem and Abd-Elrahman 2016), and consequently reduces the availability of nutrients to crop plants that needed to be absorbed.

As for the effect of organic fertilization on lettuce crop, since vermicompost, biochar or compost improved the soil nutrient status (Table 4), improvements in lettuce yield and quality were occurred (Table 5). Since some organic fertilizing sources influence soil physical properties as well as soil microbial activity (Cayuela et al. 2009; Lima et al. 2009), the application of organic fertilizers improved crop productivity greater than the chemical fertilizers (Wassie 2012). Further studies pointed out that application of slow-release

nitrogen fertilizer (organic) produced lettuce yield greater than mineral nitrogen fertilizer (Yeshiwas et al. 2018).

With moderate irrigation water supply, the action of organic fertilizers is more important, since irrigating the organically fertilized lettuce by 80% of crop evapotranspiration enhanced the lettuce yield (Table 5) with saving 20% of irrigation water. It has been demonstrated that increased application of organic fertilizer (manure) could decrease the amount of leachate (Giroto et al. 2013), due to the enhanced water-holding capacity by organic fertilizer, while inorganic fertilizer may not influence soil water-holding capacity (Li et al. 2018).

The use of slow-release fertilizers or organic manure gave high yield with low nitrate content in the leaves and decreased the loss of nitrogen into the water table, since they delayed the transformation of N into nitrate (El-Shinaway et al. 1999). Nazaryuk et al. (2002) mentioned that the poorly controlled flux of soil nitrogen resulting from active mineralization of organic matter may lead to excessive accumulation of nitrate in plants. Accordingly, accumulation of $\text{NO}_3\text{-N}$ of mineral fertilizer treatment reached about 1.24 times than organic fertilizers (Table 5). Also, lower rate of transforming N to $\text{NO}_3\text{-N}$ was observed with compost (Fig. 2).

5 Conclusions

Findings of the current research indicated that irrigating lettuce by 80% of crop evapotranspiration achieved yield and nutritional value like the full irrigation (100%). Accumulation of nitrate in lettuce leaves was higher with the application of mineral fertilizers than organic ones. Hence, application of compost with irrigation by 80% of crop evapotranspiration showed promising solution to reduce the accumulation of nitrate in lettuce. The equilibrium between soil water and soil nutrition can be achieved by irrigating the organically fertilized lettuce using 80% of crop evapotranspiration instead of 100%. Also, it is obvious that dispensing with mineral fertilizers and substituting them with vermicompost or biochar can be applied in the fertilization program for higher productivity of lettuce.

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Declarations

Disclosure Statement The authors declare that they have no conflict of interests concerning the current research publication.

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