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RESEARCH ARTICLE

ESTIMATED WATER FOOTPRINT AND CARBON DIOXIDE EMISSION FOR GARLIC UNDER DIFFERENT LEVELS OF IRRIGATION AND NITROGEN

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ABSTRACT

A worldwide indication of the amount of water used in the manufacturing cycle of commodities is called the "Water Footprint." The entire amount of freshwater used or contaminated throughout a commodity's manufacturing is known as its "water footprint." Water consumption mostly refers to the amount of water that plants need during the growth season (green and blue water), whereas water pollution (gray water) is primarily caused by fertilizer seeping from the field. To investigate the effects of varying irrigation and nitrogen dosage levels on vegetative growth characteristics, yield parameters, and chemical contents, an experiment was conducted on garlic plants during the two winter seasons of 2020–2021 and 2021–2022, at the Central Laboratory for Agricultural Climate (CLAC) research site, Dokki, Giza, Egypt. To investigate the effects of varying irrigation levels and nitrogen doses on vegetative growth characteristics, yield parameters, and chemical contents of garlic. The nitrous oxide (N_2O) and water footprint (WFP) emissions were estimated using the collected data. Two elements make up the treatments: three main plots with irrigation levels of 80, 100, and 120% of the required water, and three subplots with nitrogen levels of 60, 80, and 100 kg doses, each three duplicated in a split-plot design. The findings demonstrated that under irrigation, the highest vegetative growth parameters, yield parameters, and chemical composition of leaves were observed. The results demonstrated that, at an irrigation level of 120% of the water requirements and 100 kg of nitrogen dose for the garlic plant, the highest vegetative growth characteristics, yield parameters, and chemical contents of leaves were recorded. The relationship between nitrogen doses and irrigation levels reveals that, when combined, 120% irrigation levels and 100 kg of nitrogen dose produced high yield parameters, vegetative growth characteristics, and chemical content in the leaves; this was followed by 100% irrigation levels and 100 kg of nitrogen dose with notable differences between the two. In all measurements, the combination of 80% irrigation levels and a 60kg nitrogen injection yielded the lowest value. Under 120% irrigation and 60 kg of nitrogen fertilizer, the water footprint for the output of fresh and cured garlic was higher, measuring 628 m^3/ton and 959 m^3/ton, respectively. The maximum emission of N_2O with 100 kg of nitrogen and an irrigation level of 80%, the highest N_2O emission value for cured garlic yield, was reported at 0.283 kg N_2O per ton of cured garlic output, or 84.5 kg CO_2/ton. With 100 kg of nitrogen and an irrigation level of 80%, the greatest N_2O emission value for fresh garlic output was reported at 0.190 kg N_2O per ton, or 56.7 kg CO_2/ton.

KEYWORDS

N_2O, garlic, water footprint, irrigation amount, nitrogen dose, loamy soil, and CO_2 equivalent emission.

1. INTRODUCTION

The Allium genus contains approximately 600 species, and the bulbous spice crop known as garlic (Allium sativum L.) is a member of this family. For thousands of years, it has been utilized as a medicinal plant and flavoring in food by numerous cultures. It After onions, it is the crop that is grown the second most frequently (Hamma et al., 2013). Garlic is one of the primary vegetable crops grown in Egypt, either for domestic use or export. Egypt is the fifth-largest producer of garlic in the world (333.543 tons), behind South Korea, China, India, and Bangladesh (FAOSTAT, 2020). Garlic is employed as an antifungal and antibacterial in the medical profession and is used in the treatment of chronic stomach diseases, according to studies (Efionget et al., 2020; Metwaly et al., 2020). In dry and semi-arid areas, a major problem is frequently the limited supply of water (Abu-hashim and Shaban, 2017). The generally acknowledged rise in living standards has led to an increase in the demand for water, particularly in the agricultural sector (Yakubu and Karaye, 2007).

Good irrigation management is thought to be one of the key agricultural practices influencing the growth, development, final bulb output, and quality of garlic and onion (Karaye and Yakubu, 2007; Ali et al., 2020). Garlic needs regular irrigation and enough moisture because it is sensitive to water deficits. This will increase crop yield and improve bulb quality. Garlic's growth, yield, and characteristics that contribute to yield were all increased by using a drip system and implementing a 100% ETc (actual evapotranspiration) regime, according to (Mandefro and Quraishi, 2015). This method is also more efficient than surface irrigation. Because nitrogen fertilizer increases crop yield, it is important to agriculture. Fertilizer enriched with nitrogen increases food quality and quantity in addition to yield. The optimal nitrogen rate boosts photosynthetic processes in leaves.

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The optimal nitrogen rate boosts net assimilation rate, leaf area production, leaf area duration, and photosynthetic activities. The best yield was achieved with a high N treatment of 300 kg N/ha. Garlic has a high N requirement, especially in the early growth stage (Maryam et al., 2012). Additionally, a group researchers found that when the nitrogen rate was increased from 60 to 180 kg/ha, there was an increase in the length, number, and fresh bulb output of garlic (Tibebu et al., 2014). Plots fertilized with nitrogen and phosphorus at a dose of 92 N and 46 P2O5 kg/ha had the maximum bulb production, 7.11 t/ha (Workat et al., 2018). According to to a study, the height, quantity of cloves, and diameter of garlic plants (Sitaula et al., 2020).

Increases in nitrogen fertilizer dosage were observed to improve garlic plant height, clove count, bulb diameter, fresh bulb weight, and overall bulb output (Sitaula et al., 2020). In their study, Fatideh and Asil examined several water (0.50, 0.80, 1.10, and 1.40 pan evaporation "PE") and nitrogen regimes (50, 100, and 150 kg ha-1) for the development of high-quality onions (Fatideh and Asil, 2012). They discovered that high bulb weight and yield were achieved with irrigation at 1.40 PE and nitrogen at 150 kg/ha. Four water levels—50%, 75%, 100%, 100% (I3), and 100% (I4)—as well as four nitrogen levels—25% (N1), 50% (N2), 75% (N3), and 100% (N4)—of nitrogen fertilizer demand are assessed (Piri and Naserin, 2020). The quantity of nitrogen sprayed and irrigation water used had The quantity of nitrogen applied and irrigation water had a substantial impact on every assessed onion yield. Onion bulbs with 100% nitrogen irrigation had the biggest diameter and the tallest bulbs with 100% nitrogen irrigation, respectively.

A concept used to indicate the amount of water used in the production chain of commodities is called the Water Footprint (WFP) idea. The entire amount of freshwater used or contaminated over the course of a commodity's manufacturing is known as its "water footprint." Water consumption for agricultural crops mostly refers to the amount of water used by the plants (green and blue water) throughout the growing season, whereas water pollution (gray water) is primarily caused by fertilizer seeping from the field. A crop's water footprint is the outcome. Crop evapotranspiration throughout the growing season and the yield obtained from the amount of water consumed combine to form the water footprint. Weather variability should therefore be taken into account when estimating the water footprint because it affects water consumption through microclimates, which in turn affects planning for water supplies at both the farm and regional levels (El-Marsafawy et al., 2018). According to a study, WF separates water consumption into three categories: green, blue, and gray water, which are characterized both spatially and temporally (Mekonen and Hoekstra, 2011). Agronomic water productivity (WP), which is measured in kilograms of yield production per volume (m3) of water received by the crop, is a technique that can boost water-use efficiency and improve the water footprint (WFP) (Abu-Hashim and Shaban, 2017). The process's estimated overall water footprint (WFprocess)

According to estimates from the total water footprint of the process (WFprocess) for garlic varied from about 350 m3 Mg-1 to 475 m3 Mg-1 (Mekonnen and Hoekstra, 2010; Fernándeza et al., 2020). A few agricultural practices that have an impact on the grey water footprint (GWF) are the amount and type of nitrogen fertilizer applied, the degree of tillage, the treatment of pests and diseases, and irrigation practices (quantity and quality of water applied). Plant growth will be inhibited by a low nitrogen application dose, which will reduce agricultural yield production. Water pollution per hectare will decrease as a result. Up to a certain point, a high nitrogen application dose will create a high yield together with an upper level of pollutants per hectare and per ton of yield produced (Raun et al., 2002).

A temperature range that is regulated by the greenhouse effect is necessary for crop growth. The rise in global temperature has been linked to changes in the concentration of greenhouse gases (GHG), primarily carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), which have occurred in recent years. N2O stands out among those gases due to its ability to last over 114 years in the atmosphere and its 298-fold higher warming potential than that of CO2.Approximately 87.2% of N2O emissions came from the agriculture sector, primarily from the management of animal waste and agricultural soils, particularly the use of nitrogen fertilizer (Cerri et al., 2009). Nitrous oxide emissions from agricultural soil deplete nitrogen reserves and are a major contributor to global warming. Diminishing the soil.

N2O emissions can be reduced by substantially inhibiting the nitrification and denitrification pathways by lowering the NH+4 and NO−3 concentrations of the soil (Coskun et al., 2017). Nitrogen application mostly results in an oversupply of dissolved inorganic N in the topsoil due to crop production, which lowers the efficiency of nitrogen use and raises emissions of N2O (Wu et al., 2021). The objective of this study was to investigate the correlations between various irrigation and nitrogen dose levels in order to compute the water footprint and N2O emissions for garlic output.

2. Materials And Methods

2.1 In-situ experimental processes

In order to investigate the impact of varying irrigation levels and nitrogen dosages on garlic yield as well as carbon dioxide emissions, a field experiment was granted at the Central Laboratory for Agricultural Climate (CLAC) experimental location, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Giza Governorate, Egypt 30.04588 N and 31.20463 E., during two winter seasons of 2020–2021 and 2021–2022. In the two seasons of 2020 and 2021, the 25th of September saw the planting of the Balady cultivar garlic cloves. The beds were made one meter wide in order to cultivate garlic. Watering was done with two polyethylene lines.

Each bed received two 16 mm-diameter polyethylene lines for irrigation, with emitters spaced 30 centimeters apart each. There was a 4 l/hr emitter discharge rate. There were four rows of garlic plants in each bed. There was a 20 cm gap between each row and a 15 cm gap between two plants in a row. The loamy soil was chosen for the experimental study. The physical and chemical analyses of the soil were measured prior to cultivation (Table 1). Chemical properties were identified. As stated by A.O.A.C. (1990). Physical properties of the soil were measured, including bulk density Mg/m3 (BD), saturation point (SP), wilting point (WP), and field capacity (FC). Most crops can be grown in the loamy soil that extends down to 0.3 meters. Such soil has effective soil properties, like a balanced capacity to hold water and air. The results of the experiment show that the soil in that location is somewhat alkaline.

By measuring the amount of water needed to absorb the nutrients that reach the round- or surface-water, the gray water footprint of agricultural production—a measurement of the amount of freshwater pollution—is computed. The primary cause of non-point source pollution of surface and underground water bodies is nutrient leakage from agricultural areas. Mekonnen and Hoekstra state that the amount of water required to absorb the nutrients that end up in surface or ground water is how the grey water footprint is determined (Mekonnen and Hoekstra, 2011). The primary cause of non-point source pollution of surface and underground water bodies is nutrient leakage from agricultural areas. The majority of research quantify the gray water footprint solely in relation to nitrogen utilization. The gray part of

By multiplying the fraction (f) of nitrogen that leaches or runs off by the nitrogen application rate (LN), dividing this result by the difference between the maximum acceptable concentration of nitrogen (nitrogen NO3-N) and the natural concentration of nitrogen (CN, nat) in the receiving water body, and finally dividing the result by the actual crop yield (Y), one can compute the grey component of the water footprint (GWF). Naturally, one has to have a solid idea of both the rate at which nitrogen fertilizer is applied to a certain crop and the amount of nitrogen fertilizer that is lost to leaching in order to calculate an accurate estimate of the crop's grey water footprint.

"GWF" = ("f " .L_N)/(("C" _(N, max)-C_(N, net))."Y")

The grey water footprint calculation is the values of CN, nat and CN., max in the receiving water bodies. Until recently, most published articles that present calculations of the grey water footprint would consistently report the value of zero for CN, n (Mekonnen, and Hoekstra, 2001). For the maximum concentration, CN, max, stated that the recommended maximum value of nitrate in surface and groundwater by the World Health Organization and the European Union is 50 mg nitrate (NO_3) per L, and the maximum value recommended by US-EPA is 10 mg/L measured as nitrate-nitrogen (NO_3-N); thus, in most studies, the standard of 10 mg/L NO_3-N is used following a study which is a reasonable assumption (Chapagain et al., 2006).

2.2 Total Water Footprint

An annual total WF was calculated for garlic under different levels of irrigation and nitrogen according to the following formula (Hoekstra et al., 2011).

WF = WF green + WF blue +WF grey

2.3 Nitrous oxide (N_2O) from synthetic fertilizers applied on soils

Emissions relevant to the garlic crop described in this paper are CO_2 eq and N2O. Both CO_2 eq and N_2O emissions mainly arise from cultivation practices (nitrogen fertilizer application). The calculation of N2O and CO_2 eq according to Guidelines for Greenhouse Gas Inventories (IPCC, 2006). The amount of N_2O emitted from the application of artificial fertilizers is:

N_2O fertile = M fertile * (1- fr atm, f) * Efactor * (M N_2O / M N2) * GWP N_2O

Where:

M fertile = mass of nitrogen in fertilizer needed to produce the amount of product analyzed (kg N applied per ton harvest)

fr atm, f = fraction of nitrogen that is released into the atmosphere as NH_3 or NOx, (IPCC, 2006)

E factor = emission factor for fertilizer, i.e. kg of N_2O-N per kg N applied (IPCC, 2006)

M N_2O / M N_2 = 44/28 is the mass ratio of N_2O and N2

GWP N_2O = Greenhouse Warming Potential of N_2O with respect to CO_2

The result for total yield is in units of kg CO_2-equivalents per ton harvest.

2.4 The Experimental design

The treatments of the experiment were arranged in a split-plot design in three replicates. The irrigation levels were arranged as a main plot and nitrogen as a subplot.

The statistical analysis:

Data were statistically analyzed using the Statistical Analysis System (SAS) program (SAS, 2000). The differences among means for all traits were tested for significance at a 5 % level, according to (Waller and Duncan, 1969).

3. Results And Discussions

3.1 Vegetative growth characters

The effect of irrigation levels and nitrogen dose and their interaction with them on vegetative growth (plant height, number of leaves fresh and dry weight per plant) of garlic plants were presented in Table 2. Regarding the impact of irrigation level, the studied vegetative development characteristics were significantly impacted by the treatments. Nonetheless, the highest values of vegetative growth parameters were produced by irrigating garlic plants with a 120% water demand, followed by 100% water requirements. Garlic plants that demand 80% of the water during irrigation had the lowest values for these characteristics. In the second season, the same outcomes were achieved. These outcomes might be the consequence of water's beneficial effects on turgor pressure maintenance in cells and nutrient movement inside plants, which enhanced the area of green tissue and enhanced photosynthetic absorption, both of which promoted plant growth. However, when plants are stressed by water, their stomata close, which reduces their ability to absorb CO2 and nutrients. Consequently, photosynthesis and additional biological.

Consequently, the cessation of photosynthesis and other biochemical processes has an adverse effect on the growth of plants. These findings are consistent with the research conducted on onions, garlic, and on onions (Der et al., 2018; Bagali et al., 2012; Pooja et al., 2018). Regarding the influence of nitrogen dose, the findings indicated that the applied nitrogen dose had an impact on the vegetative growth features, which were considerably higher at a higher nitrogen dose (100 kg). Using 80 kg in descending order yielded the lowest value, followed by 60 kg. The involvement of nitrogen in speeding the synthesis of plant proteins, chlorophyll, and enzymes as well as increasing the area of green leaves, which in turn aided to enhance the synthesis of carbohydrates and lead to faster growth, may be the cause of the increase in vegetative growth as the nitrogen dose increases. This interpretation is in line with studies on garlic plants (Shafeek et al., 2021; Lata et al., 2023; Prabhakar et al., 2011; Kakade et al., 2015).

Additional researchers examined the impact of varying nitrogen concentrations on garlic plants and found that increasing nitrogen levels from 0 to 200 kg N ha-1 boosted the plants' vegetative development (Zaki et al., 2014; Zaman et al., 2011). About the way that the amount of irrigation and the dose of nitrogen interact. Vegetative development factors (plant height, number of fresh leaves, and dry weight per plant) were significantly impacted. The application of 120% water requirements along with 100 kg of nitrogen resulted in the greatest values of these metrics, with fresh leaf weight being the only treatment that showed a meaningful difference. When paired with an 80 kg nitrogen treatment, the 120% water requirements did not significantly alter the results.

This might be the outcome of better photosynthesis and photosynthetic accumulation during the growth phase, which encouraged vegetative growth. Water and nutrients were also available at this time. According to some study for garlic and onions, these results are consistent (Der et al., 2018; Gebregwergis et al., 2015). A group researcher examined the effects on onion plant height, leaf length, and fresh and dry leaf weight of different nitrogen fertigation rates (75, 100, 125, and 150 kg/ha) and irrigation levels (60, 80, 100, and 120%) (Pooja et al., 2018). With the exception of plant height, they discovered that the combination of nitrogen fertigation at 150 kg/ha and irrigation levels at 120% produced the maximum vegetative growth.

The information shown in Table 5 demonstrates how various irrigation schedules and nitrogen dosages affect yield as well as its constituent parts (fresh yield, cured yield, and yield weight loss percentage after cured). When it came to the impact of irrigation levels, the data gathered indicated that applying 120% of the water requirements produced the highest fresh yield per feddan, followed by applying 100% of the water requirements, and applying 80% of the water requirements produced the lowest fresh yield per feddan, with a significant difference between them. However, applying 100% and 120% of the required water resulted in the best cured yields, with no discernible difference between the two. Furthermore, when irrigation levels rose from 80% to 120% of the required water, the yield of garlic after curing showed a substantial rise in loss weight percentage.

Put another way, the garlic yield that lost the least amount of weight after curing was when 80% of the required water was applied. Conversely, the application of 120% of the required water was found to result in the highest percentage of weight reduction. This yield increase may have been caused by the effect of adequate irrigation on achieving vigorous vegetative growth in garlic. This helped the plant produce more photosynthesis, which in turn increased the amount of carbohydrates and other metabolites that accumulated and increased the yield. These outcomes correspond with those in garlic, in onion (Ahmed et al., 2009; Gajbhiye et al., 2009; Tripathi et al., 2010; Yadav et al., 2010). Also, a group researchers investigated the impact of different irrigation levels (50%, 75%, and 100%) on water requirement (Abu-Hashim and Shaban, 2017; Metwaly, et al., 2020). The results show that the fresh yield and cured yield of garlic were increased in parallel with an increased amount of water irrigation. While the average weight loss percent of cured yield was decreased in parallel with decreasing irrigation water quantity.

Regarding the effect of nitrogen dose, data from both seasons showed that increasing the nitrogen dose from 60 kg to 100 kg increased the yield after curing and the fresh yield, but it increased the yield's weight loss percentage after curing negatively. This is due to the fact that an ideal nitrogen supply is essential to the growth of leaves in terms of quantity, size, and length. Consequently, increased light absorption and improved light utilization for photosynthesis inside the plant lead to an increase in yield. This explanation is in line with the findings of Fathi, who stated that nitrogen is crucial for raising the amount of chlorophyll in leaves, which in turn affects photosynthesis rate and plant productivity (Fathi, 2022). These findings were in line with those of who examined the effects of four nitrogen fertilizers (0 kg, 50 kg, 100 kg, and 150 kg N ha-1) and found that raising the rate of fertilizer to 150 kg N ha-1 enhanced the overall production of garlic (Lata et al., 2023). Other researchers have also discovered that nitrogen is beneficial for other bulbous crops, such onions. A group researcers and others have shown that when the plants are given the right amount of nitrogen, the production of onions increases dramatically (Girmay, 2020; Piri and Naserin, 2020).

The garlic plants that were irrigated with 1/20th of the water required and 100% of the nitrogen dose yielded the most fresh yield due to the interaction between irrigation levels and nitrogen dose. The combination of 120% and 100% of water requirements and 100 kg of nitrogen produced the highest estimated cured yield, followed by 120% of water requirements and 80 kg of nitrogen, with no discernible difference between the two. The highest weight loss percentage of garlic yield was obtained after curing in comparison to other treatments. However, when 80% of the water required for irrigation was paired with 60 kg of nitrogen, the garlic yield—both fresh and cured—was lowest, as was the percentage of weight loss after curing. Piri and Naserin discovered similar outcomes when they examined the effects of four different crop water requirements:

50% (I1), 75% (I2), 100% (I3), and 120% (I4); and four different applied nitrogen levels: 25% (N1), 50% (N2), 75% (N3), and 100% (N4) of N fertilizer required on onion plants (Piri and Naserin, 2020). They discovered that the highest yield was obtained at I3N4, followed by I4N4 with no significant difference between them.

This outcome is because the availability of soil water and the uptake of nutrients by plants, such as nitrogen, are directly correlated. Plants that receive insufficient water have a reduced ability to absorb nitrogen from the soil. However, some of the soil's nitrogen is lost by leaching when the water supply is increased over what is necessary. The lack of nitrogen in both situations impairs the ability of photosynthetic accumulation and the photosynthesis process, which lowers production. Therefore, it is necessary to determine the ideal ratio of nitrogen and water while also taking the economy into account.

Table 1: Effect of irrigation level and nitrogen dose on yield and its component of garlic during the two seasons of 2020/2021 and 2021/2022.

Treatments		First season			Second season		
		Fresh yield (Ton/feddan)	Cured yield. (Ton/feddan)	Weight loss%	Fresh yield (Ton/feddan)	Cured yield. (Ton/feddan)	Weight loss%
		Irrigation level					
80 %		9.5 C	6.50 C	31.4 C	9.4 C	6.31 C	32.4 C
100%		11.1 B	7.47 B	32.3 B	11.8 B	7.80 B	34.1 B
120%		12.3 A	7.93 A	35.5 A	13.3 A	8.50 A	36.1 A
		Nitrogen rate					
60 %		9.4 C	6.40 C	31.4 C	9.6 C	6.37 C	33.4 C
80 %		11.3 B	7.49 B	33.5 B	11.8 B	7.76 B	34.2 B
100%		12.2 A	8.01 A	34.2 A	13.1 A	8.47 A	35.0 A
		Irrigation level * Nitrogen rate					
80 %	60 %	7.8 e	5.44 f	30.2 f	7.5 f	5.13 f	31.4 e
	80 %	9.9 d	6.76 de	31.8 de	10.0 e	6.75 de	32.4 de
	100 %	10.8 c	7.30 c	32.2 cd	10.6 de	7.07 de	33.2 d
100%	60 %	9.3 d	6.47 e	30.5 ef	10.0 e	6.63 e	33.4 d
	80 %	11.4 c	7.64 bc	33.1 cd	11.7 c	7.75 c	34.0 cd
	100 %	12.4 b	8.30 a	33.2 cd	13.8 ab	9.00 ab	34.9 bc
120%	60 %	11.0 c	7.30 cd	33.6 c	11.4 cd	7.36 cd	35.3 bc
	80 %	12.5 b	8.07 ab	35.7 b	13.7 b	8.79 b	36.0 ab
	100 %	13.4 a	8.41 a	37.4 a	14.8 a	9.35 a	37.0 a

Feddan = 0.42 ha

3.2 Chemical contents of leaves

Table 2 : Effect of different irrigation levels and nitrogen doses on N, P, and K % contents of garlic leaves.

Treatments		First season			Second season		
		N%	P%	K%	N%	P%	K%
		Irrigation level					
80 %		3.52 C	0.39 C	3.43 C	3.64 C	0.38 C	3.41 C
100 %		4.11 B	0.41 B	3.86 B	3.94 B	0.41 B	3.82 B
120 %		4.24 A	0.45 A	4.12 A	4.18 A	0.43 A	4.13 A
		Nitrogen rate					
60 %		3.48 C	0.35 C	3.56 C	3.59 C	0.35 C	3.51 C
80 %		4.08 B	0.41 B	3.78 B	3.95 B	0.40 B	3.78 B
100 %		4.32 A	0.49 A	4.07 A	4.22 A	0.47 A	4.07 A
		Irrigation level * Nitrogen rate					
80 %	60 %	2.86 f	0.31 e	3.10 g	3.21 e	0.31 e	3.03 f
	80 %	3.68 e	0.39 d	3.40 f	3.69 cd	0.38 cd	3.47 e
	100 %	4.04 d	0.46 bc	3.79 de	4.01 b	0.45 ab	3.73 de
100 %	60 %	3.68 e	0.34 e	3.65 e	3.64 d	0.36 d	3.66 de
	80 %	4.24 c	0.42 cd	3.82 cd	4.00 b	0.41 bc	3.74 de
	100 %	4.41 ab	0.48 ab	4.12 b	4.20 ab	0.47 a	4.06 bc
120 %	60 %	3.91 d	0.41 d	3.93 c	3.94 bc	0.39 cd	3.84 cd
	80 %	4.31 bc	0.43 cd	4.13 b	4.18 b	0.42 bc	4.12 b
	100 %	4.51 a	0.52 a	4.32 a	4.44 a	0.49 a	4.42 a

Regarding the effect of irrigation levels, the data showed this. The highest percentage of nitrogen, phosphorus, and potassium content was recorded in irrigated plants at 120%, followed by 100% of the water requirements with significant differences between them while the lowest content of N, P, and K in garlic leaves was found in irrigated plants by 80% of water requirements.

This could be because the right quantity of moisture was present in the soil, creating ideal circumstances for improved root development and nutrient mobility, which in turn led to increased plant uptake of the elements. According to many study this interpretation was comparable (Raman and Reddy, 2013; Ezzo et al., 2010; Ali et al., 2020).

With regard to the impact of nitrogen dosage, the data unequivocally demonstrated that the percentages of N, P, and K in garlic leaves increased as the nitrogen dose of fertilizer increased from 60 kg to 100 kg, with notable variations between them. The two seasons' outcomes complement one another.

These findings could be explained by the fact that adding more nitrogen fertilizer to the soil solution increased nutrient availability, which promoted improved absorption and raised the concentration of nutrients in storage organs. The findings of some study are highly compatible with this one (Shafeek et al., 2020; Abuhashim et al., 2023).

In terms of the interactions between irrigation levels and nitrogen dose, plants that received irrigation at 120% or 100% of their water requirements together with 100 kg of nitrogen had the highest levels of content in terms of nitrogen, phosphorous, and potassium. Nevertheless, a statistical analysis of the data showed that while the potassium content varied significantly between the two prior treatments, the levels of phosphorus and nitrogen did not significantly alter.

Garlic leaves with the lowest NPK content were those with the lowest irrigation level (80%) and nitrogen dose (60 kg). a group researchers reported similar outcomes and explained the interaction between irrigation and N levels on nutrient uptake by pointing to the importance of optimal moisture availability in the soil for enhancing nitrogen uptake, which in turn permitted an increase in root spread and encouraged a higher uptake of water and nutrients (Samir et al., 2019). Therefore, in dry soil, plant roots cannot receive the ideal quantity of nitrogen, which leads to poor root spread and nutrient absorption.

3.3 The Water Footprint

The blue water footprint for fresh garlic yield was lower at 80% irrigation with nitrogen fertilizer 100 kg recorded at 259 m3/ton, followed by 100% irrigation with nitrogen fertilizer 100 kg recorded at 264 m3/ton, as shown in Figure (1), which displays the blue water footprint under various irrigation levels and nitrogen doses. At 120% irrigation level and 60 kg of nitrogen fertilizer, the greatest garlic blue water footprint was measured at 271 m3/ton. When using 120% irrigation and 60 kilogram of nitrogen fertilizer, the gray water footprint was larger, measuring roughly 257 m3/ton, however when using 80% irrigation and 100 kg of nitrogen fertilizer, the gray water footprint was lower, measuring 179 m3/ton.

Fresh garlic yields under 120% irrigation had a larger total water footprint, and 628 m3/ton of nitrogen fertilizer was used. However, the overall water footprint was reduced to 80% when using 100 kg of nitrogen fertilizer for irrigation, or 438 m3/ton. The blue water footprint for curl garlic production was lower at 80% irrigation with nitrogen fertilizer of 100 kg measured at 385 m3/ton, as shown in Figure (2), which also included data on nitrogen dose and irrigation levels. At 120% irrigation level and 60 kg of nitrogen fertilizer, the greatest garlic blue water footprint was measured at 566 m3/ton.

About 393 m3/ton of gray water was recorded under 120% irrigation with 60 kg of nitrogen fertilizer, whereas 267 m3/ton of gray water was reported under 80% irrigation with 100 kg of nitrogen fertilizer. Curly garlic output required less water overall—less than 120% irrigation—and 60 kg of nitrogen fertilizer—959 m3/ton—was reported. However, the overall water footprint was reduced to 80% when 652 m3/ton of nitrogen fertilizer (100 kg) was used for irrigation.

When there is neither water stress nor nitrogen stress, full irrigation, and a high rate of nitrogen delivery, garlic yields best. The condition of optimal irrigation level and N application dosage resulted in the maximum yield. the decreased production of garlic with various nitrogen treatments due to low or nitrogen-stressed levels. Deficit irrigation can cause some water stress in addition to the drop in garlic yield, although crop yield is limited by nitrogen at such high levels of stress. This indicates that the primary determinants of water footprint were nitrogen and irrigation.

This outcome is consistent with the findings of who found that increasing the dosage of nitrogen fertilizer can raise the values of the grey water footprint and that the primary factor influencing the grey water footprint is the amount of nitrogen administered (Luciana et al., 2021). Utilizing appropriate nitrogen levels and irrigation techniques boosts agricultural yield and decreases non-recoverable water losses, which lowers the water footprint, according to several studies conducted on a variety of crops in Egypt. Better crop varieties and agronomic approaches, such as irrigation techniques, nitrogen dosage, and management, particularly fertilizer management, are probably to blame for the WF reduction. Swelam & Associates, 2022. Garlic's total water footprint was estimated to be between 350 and 475 m3 Mg-1, whereas its value was 589 m^3 Mg^{-1} estimated (Léllis et al., 2022; Mekonnen and Hoekstra, 2010).

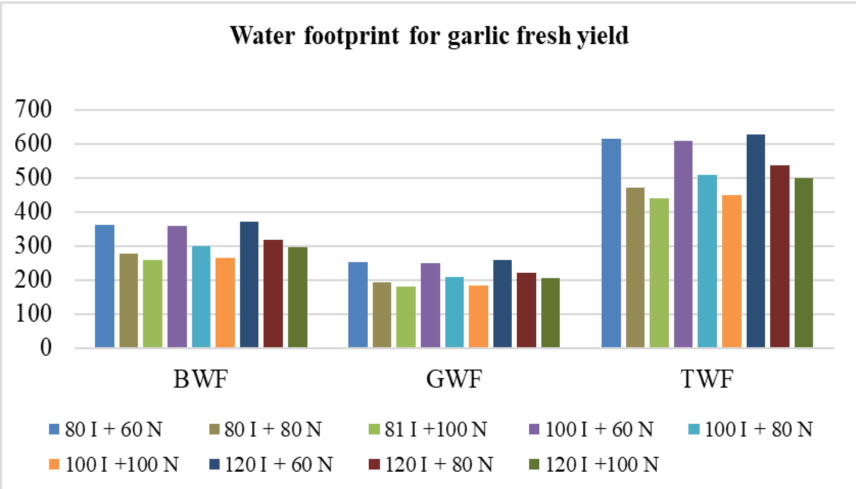

Figure 1: The effect of different levels of irrigation and nitrogen on blue water footprint (BWF), gray water footprint (GWF) and water footprint (WFP) for fresh garlic yield for the average of two growing seasons.

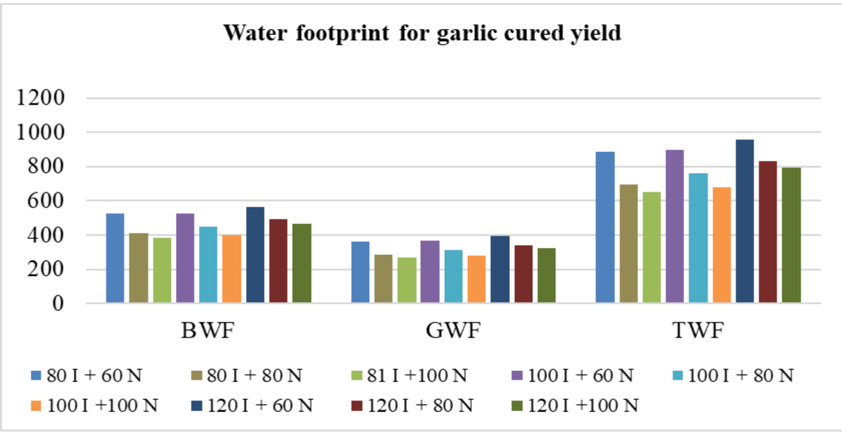

Figure 2: The effect of different levels of irrigation and nitrogen on blue water footprint (BWF), gray water footprint (GWF), and water footprint (WFP) for curl garlic yield for the average of two growing seasons.

3.4 N_2O and CO_2 -equivalents emission from nitrogen fertilizers

The presented data in Table (3) show the effect of different irrigation levels and nitrogen doses on the N_2O emission for fresh garlic yield. The highest N_2O emission value for yield obtained under 80 % irrigation level with 100kg nitrogen recorded about 0.190 Kg N_2O/ton fresh garlic yield equal to 56.7 Kg CO_2/ton fresh garlic yield followed by 80 % irrigation level with 80 kg nitrogen recorded about 50.8 Kg N_2O/ton fresh garlic yield equal to 56.7 Kg CO_2/ton fresh garlic yield. The lowest N_2O emission value for fresh garlic yield was obtained under 120% irrigation level with 60 kg nitrogen recorded at about 0.121 Kg N_2O/ton, equal to 36.1 Kg CO_2/ton fresh garlic yield the obtained results were relevant with the findings of (Abu-Hashim et al., 2016; Mohamed et al., 2019; Alnaimy et al., 2020).

Table 3: The effect of different levels of irrigation and nitrogen on the emission of N_2O and CO_2 (Kg/ton) in fresh garlic yield for the average of growing seasons.

Irrigation levels (%)	Nitrogen dose (Kg)	fresh yield Ton/fed.	N_2O emission kg per kg garlic	CO_2-equ kg per kg garlic
80%	60	7.65	0.177	52.9
	80	9.95	0.171	50.8
	100	10.70	0.190	56.7
100%	60	9.65	0.141	41.9
	80	11.55	0.147	43.8
	100	13.10	0.155	46.3
120%	60	11.20	0.121	36.1
	80	13.10	0.130	38.6
	100	14.10	0.144	43.0

Feddan=0.42 ha

Table (4) shows the effect of different irrigation levels and nitrogen doses on the N_2O emission for cured garlic yield. The highest N_2O emission value for yield obtained under 80 % irrigation level with 100 kg nitrogen recorded about 0.283 Kg N_2O/ton cured garlic yield, equal to 84.5 Kg CO_2/ton cured garlic yield. The lowest N_2O emission value for fresh garlic yield obtained under 120 % irrigation level with 60 kg nitrogen recorded about 0.185 Kg N_2O/ton, equal to 55.2 Kg CO_2/ton cured garlic yield.

Because the loss of humidity in curl yield resulted in lower output with the same amount of nitrogen levels employed in the emission calculation equation, which raised emission for each ton production, the N2O and CO2 emissions were higher in curl yield than in fresh yield. While boosting productivity and improving the efficiency of nitrogen use by efficient agricultural practices can have unfavorable effects, all prior research has demonstrated a linear link between increasing the rate of nitrogen used in fertilization and increasing emissions. Soil microbial processes of nitrification and denitrification have a significant impact on nitrogen fertilizer-induced direct N2O emissions from agricultural fields. These processes depend on a number of variables, including agricultural management techniques.

(such as fertilizer type and rate), soil physicochemical properties, and meteorological conditions (such as temperature and moisture). With respect to agricultural practices, soil NO and N_2O emissions generally increase with the increase of the N-applied rate, (Signor et al., 2013). A group researchers observed that these trace emissions may exhibit a non-linear threshold response to the N-applied rate of fertilizers (Yao, et al., 2017).

Table 4: The effect of different levels of irrigation and nitrogen on the emission of N_2O and CO_2 (Kg/ton) in curl garlic yield for the average of growing seasons.

Irrigation levels (%)	Nitrogen dose (Kg)	cured yield. Ton/fed.	N_2O emission kg per kg garlic	CO_2-equ kg per kg garlic
80%	60	5.29	0.257	76.6
	80	6.76	0.251	74.9
	100	7.19	0.283	84.5
100%	60	6.55	0.207	61.8
	80	7.70	0.221	65.7
	100	8.65	0.235	70.2
120%	60	7.33	0.185	55.2
	80	8.43	0.201	60.0
	100	8.88	0.229	68.3

Feddan = 0.42 ha

4. Conclusion

Because there was a smaller performance gap between adequate nutrition and water supply, garlic output increased significantly with enough N supply and optimal irrigation level. The highest fresh yield was produced by garlic plants that were irrigated at 100% of the required irrigation level plus 100 kg of nitrogen. For the cured yield, there was no discernible difference between the 100% and 120% irrigation levels under 100 kg of nitrogen. Because of its great potential to cause global warming (298 times greater than that of CO2), nitrous oxide is a significant greenhouse gas. The primary sources of N2O in the atmosphere are agricultural soils and nitrogen fertilizer. The basic mechanisms influencing the generation of N2O are regulated by a number of variables that can be altered by nitrogen fertilizer management techniques. The study looks into the effects of different irrigation rates and nitrogen doses on garlic's emissions of nitrogen fertilizer. The maximum N2O emission value was observed at 80% irrigation and 100 kg of nitrogen, producing 56.7 kg of CO2 per tonne of fresh garlic. The lowest emission value was found at 36.1 kg CO2/ton fresh garlic under 120% irrigation and 60 kg nitrogen. At less than 120% irrigation, the fresh garlic output had a larger total water footprint; at 80% irrigation, it was smaller. When there was no water stress nor nitrogen stress, full irrigation, and a high rate of nitrogen delivery, the best yield for garlic was discovered. The study also discovered that the primary factor influencing the grey water footprint is the amount of nitrogen injected. It is possible to create a balance between the high garlic output, water footprint, and carbon dioxide emission in garlic growing under Egyptian conditions with highly managed irrigation practices and optimal nitrogen rates, although further research is needed in this area.

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