Middle East Journal of Agriculture Research
Volume: 11 | Issue: 01| Jan. – Mar.| 2022

EISSN: 2706-7955 ISSN: 2077-4605
DOI: 10.36632/mejar/2022.11.1.9
Journal homepage: www.curresweb.com
Pages: 89-102

Appropriate Ammonium-Nitrate Ratio Improves Vegetative Growth and Yield of Eggplant under Water Stress Conditions

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Received: 03 Jan. 2022 **Accepted:** 15 Feb. 2022 **Published:** 20 Feb. 2022

ABSTRACT

Water deficit in arid and semiarid regions limits eggplant (*Solanum melongena* L.) productivity and growth indicators. In this work, an experiment was conducted during two studied seasons of 2020 and 2021 on the farm belonging to the Central Laboratory for Agricultural Climate, Dokki, Giza governorate, Egypt. This work aimed to study the effect of different irrigation levels and nitrogen forms on the growth and yield of eggplant (*Solanum melongena* L., c.v. *classic*). Three irrigation levels, *i.e.*, 50, 75, and 100% of irrigation requirements (IR), and three nitrogen forms, *i.e.*, ammonium sulfate $(NH_4)_2SO_4$, calcium nitrate $Ca(NO_3)_2$ and ammonium nitrate NH_4NO_3 were applied in a split-plot design with three replicates. Potential evapotranspiration (ET_o) was calculated using the Penman Monteith equation and then irrigation requirements for different irrigation rates were estimated. The obtained results showed that the highest vegetative growth, *i.e.*, number of leaves, plant height, and total fresh weight were obtained by applying irrigation level 100% of IR, but the stem diameter and total dry weight were recorded by using irrigation level 75% of IR. The irrigation level 75% of IR significantly increased total and early yield during the two successive seasons. Regarding nitrogen form treatments, the highest vegetative growth was obtained by applying ammonium nitrate to the soil, followed by calcium nitrate. The interaction effect between irrigation levels and nitrogen forms was clear with the 100% irrigation level combined with ammonium nitrate giving the highest vegetative growth. Eggplant yield took another trend, the highest yield was obtained by using ammonium nitrate fertilizer under the irrigation level 75% of IR. Water use efficiency (WUE) had the same trend, applying 75% of IR gave the highest WUE values. Application of ammonium nitrate fertilizer led to increasing WUE compared to the other treatments during the two studied seasons.

Keywords: *Solanum melongena* L., nitrogen forms, irrigation levels, water stress conditions, crop productivity.

1. Introduction

Water is a major factor of plant production all over the world, particularly in arid and semiarid regions (Tahi *et al.,* 2007). Global competition for freshwater is rising as the human population, urbanization, and industrialization grow. The gap between water supply and demand is growing. Supplemental irrigation is used in more than 40% of the world's food production (Ahmad, 2016). With limited irrigation resources in Egypt and a gradual rise in population, efficient water utilization through irrigation is becoming increasingly crucial (Abdrabbo *et al.,* 2017).

Eggplant is an important economic vegetable crop with 51.288 million tons produced worldwide. Egyptian output ranks third in the world, with 1.194 metric tons produced from 0.485 million hectares, accounting for 2.3 percent of global production (FAOSTAT, 2020). Egypt's entire agricultural area was around 108 thousand acres, producing approximately 1193 thousand tons on an annual basis at an average of 11.079 tons acre^{-1} (Ministry of Agriculture and Land Reclamation, 2013). Eggplant fruits

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are high in carbohydrates (6.4%), protein (1.3%), and fat (0.3%). They're also high in K, Ca, Mg and Fe (Zenia and Halina, 2008).

One of the keys limiting factors of eggplant production has been discovered as irrigation water availability, particularly during the summer months in arid regions. Because eggplant is extremely susceptible to drought stress, particularly during the reproductive phase (Lovelli *et al.,* 2007), the vulnerable period to water stress is extended, and a water deficit has a negative and significant impact on all yield components. Ample water supply is essential during the growth season to get a good yield. The period at the start of the blooming stage is the most susceptible to water scarcity, and maximum yield was obtained with full irrigation; virtually maximum production was typically attained when irrigation was applied to give enough water during flowering and fruiting growth stages (Abou-El-Hassan, 2015).

Plant nutrition is an important factor that improves plant productivity. Nitrogen is playing an important role for plants growth and development; therefore, it is the yield-limiting factor for plant growth in agricultural soils particularly in low organic soils (Najafva *et al.,* 2008). In addition, N is the principal of all amino acids in proteins and lipids acting as structural compounds of the chloroplast (Basela and Mahadeen, 2008). Under dryland conditions, soil moisture often limits yield. Nitrogen only increases the yield to the extent of limits imposed by the water supply. Increase water supply increased the yield potential of the crop and increased the amount of N required for optimum yield (Amiri *et al.,* 2012).

Nitrates are particularly hazardous to the environment because they are not adsorbed by the soil complex, which means that large levels of nitrates may be leached (Gao *et al.,* 2012; Wang *et al.,* 2015). In some settings, Dromantiene *et al.,* (2020) discovered that 35–70% of nitrates can be leached into soil layers deeper than 1 m. Gallucci *et al.,* (2018) showed that N losses from fertilizer range from 20 to 30%, depending on pH, N sources, and soil moisture. Because of increased nitrate leaching, N losses from fertilization procedures have been a problem in recent years (Chen *et al.,* 2015).

However, the N form is favorable for plant development, yield, and quality, which varies depending on the plant (Urlic *et al.,* 2017) and a variety of other aspects (Wada *et al.,* 2015). Providing the two types of nitrogen in a certain ratio promotes optimal development; this discovery has been documented in species (Guo *et al.,* 2007; Zhang *et al.,* 2011). Predominant sources of NH_4^+-N may also have a detrimental impact on whole plant biomass deposition in some species (Marino *et al.,* 2016); nevertheless, an optimum ammonium-nitrate ratio can improve plant tolerance to abiotic stresses in another research. In comparison to nitrate, the addition of a moderate quantity of ammonium, for example, alleviates low light intensity stress in pepper (Zhang *et al.,* 2019). The objectives of this study are to determine the effect of NH_4^+:NO_3^- ratios on plant growth, yield, and nutrient accumulation, and identify the most appropriate NH_4^+:NO_3^- ratio to improve eggplant fruit productivity grown under water stress conditions

2. Materials and Methods

2.1. Experimental site, cultivar, and cultivation

The trial took place in the Experimental Protected Cultivation Farm in Dokki, Giza, Egypt, for two seasons in 2020 and 2021. Dates for transplanting eggplant (*Solanum melongena* L., c.v. *classic*) were April 11th, 2020, and April 20th, 2021, for the first and second seasons, respectively. To evaluate the influence of nitrogen fertilizer types on vegetative development, yield, and quality of eggplant under varying irrigation levels (50, 75 and 100 % of irrigation requirements). The pH of the irrigation water was 7.09, and the electrical conductivity was 0.49 dS m^{-1}. The primary physical and chemical parameters of the investigated soil were assessed in situ and in the laboratory at the start of the field experiment, prior to cultivation, using the standard procedures defined by Page *et al.,* (1982) and Chapman & Pratt (1961). The experimental soil had a clayey texture, 9.61 g kg^{-1} organic matter, a pH of 7.72 in paste, and an EC_e of 2.65 dS m^{-1}. Table 1 shows the monthly mean weather factors, *i.e.*, maximum and minimum air temperatures, relative humidity, wind speed, and soil temperature for the studied seasons of 2020 and 2021 that were obtained from the Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt, for this area of study.

Table 1: Climatic data of the experimental site during (2020/2021**)** seasons.

Month	Max. Temp. °C	Min. temp. °C	Avg. RH %	Soil temp. °C	Wind speed m sec^{-1}
First season (2020)					
May	45.06	15.33	45.71	0.80	1.85
June	40.83	20.21	49.24	0.80	2.03
July	41.12	22.70	54.94	0.80	2.02
August	38.41	24.37	56.50	0.90	2.03
September	36.78	21.39	56.56	0.80	1.92
Second season (2021)					
May	45.68	12.75	38.28	0.60	1.84
June	39.54	21.47	50.37	0.60	1.97
July	42.87	23.13	52.79	0.60	2.02
August	42.62	22.07	53.87	0.60	2.07
September	37.99	19.55	57.64	0.70	1.97

The plants were cultivated in raised beds; the width of the raised bed was one meter with two rows of eggplant per raised bed. The number of eggplant per square meter was 2.22 plants m^{-2}.

2.2. Water requirements estimation

The total amount of irrigation water was calculated (Table 2) according to the methods described by the FAO Penman-Monteith (FAO, 1998). This method strongly predicted ET_o correctly in a wide range of sites and climates. Calculations of irrigation levels were done as follow:

$ET_c = ET_o * K_c$ …… mm day^{-1} ……………………………………………………..……………….(1)

Where:
ET_c means crop evapotranspiration (mm day^{-1}),
K_c means crop coefficient (dimensionless),
ET_o means reference crop evapotranspiration (mm day^{-1}).

The irrigation requirements (IR) for each treatment were calculated as follow:

$IR = ET_c * LR * 4000 / E_a * 1000$ ..…. (m^3 $acre^{-1}$ day^{-1})……………………………………..………(2)

Where:
LR, % = leaching requirement percentage, LR were calculated based on FAO (1998).
4000 = area of one acre.
E_a = the irrigation system's efficiency (irrigation system's efficiency assumed to be 85% of total applied water).
1000 = to convert from liter to cubic meter.

The water use efficiency (WUE) was calculated according to FAO (1982) as follows: The ratio of crop yield (y) to the total amount of irrigation water used in the field for the growth season (IR),

WUE (kg m^{-3}) = Y (kg)/ IR (m^3)…………………………………………………………………….(3)

Table 2: Water requirements (m^3 $acre^{-1}$) for eggplant during the 2020 and 2021 seasons for different irrigation treatments.

First season (2020)			**Second season (2021)**		
Irrigation treatments of IR					
50%	75%	100%	50%	75%	100%
m^3 $acre^{-1}$			**m^3 $acre^{-1}$**		
787	1180	1574	799	1198	1598

All treatments received the same amount of nitrogen 40 kg acre^{-1} (as ammonium nitrate (33% N) equal to 121.3 kg acre^{-1}, calcium nitrate (15.5% N) equal to 258.0 kg acre^{-1}, and ammonium sulfate (21% N) equal to 190.5 kg acre^{-1}). Phosphorus was applied as H_3PO_4, 61% P_2O_5, at a rate of 50 liter per acre, and potassium was added at a rate of 100 kg acre^{-1} (as K_2SO_4, 48% K_2O). The total amount of NPK at variable levels was injected directly into the mainline of the drip system in a water-soluble form using a venture tube injector. Nitrogen and other fertilizers were applied at 3-day intervals in 30 equal doses starting the first week after planting and stopped 7 days before the end of the cropping period, for both studied seasons.

2.3. Experimental design

Three irrigation levels (50, 75, and 100% of irrigation requirements) and three nitrogen forms (calcium nitrate Ca $(NO_3)_2$, ammonium sulfate $(NH_4)_2SO_4$, and ammonium nitrate NH_4NO_3) were occupied in a split-plot with three replications, with irrigation treatments in the main plots and N fertilizer forms assigned to sub-plots.

2.4. Measurements

2.4.1. Vegetative growth parameters and chlorophyll content

Samples of five plants of each experimental plot were collected at the end of the season (end of August 2020 and 2021) to determine growth parameters, *i.e.*, plant length, number of leaves, stem diameter, chlorophyll reading (SPAD), and fresh and dry weights. The SPAD value was determined as outlined by Minolta (1989).

2.4.2. Fruit yield and its quality

The fruits were collected when they had reached the full size depending on the end of physiological maturity stage. Total fruit yield was estimated during the harvest on at least 25 plants in a row in such treatments and all their replications, and data were presented as tons per acre. Fruit parameters, such as number of fruits and weight of fresh fruits, were recorded until the end of cultivated seasons.

2.4.3. Biochemical analysis of leaves

Samples of the fourth upper leaf from each treatment were oven dried at 70ºC then fine grounded and wet digested. Total NPK percentages were determined according to Cottenie *et al.,* (1982). Total nitrogen and NO_3^--N were determined by Kjeldahl method according to the procedure described by Chapman and Pratt (1961). Phosphorus percentage was determined using Spectrophotometer according to Watanabe and Olsen (1965). Potassium percentage was determined by Flame photometer as described by Chapman and Pratt (1961).

2.5. Economic study

The economic evaluation was estimated by calculating the cost of cultivation for different agro–inputs, *i.e.*, labors, irrigation, fertilizers, harvesting, and other necessary experimental requirements. Pumping water costs were divided into two main categories: (i) fixed cost and (ii) operating costs, which vary with the number of operating hours. The average cost of pumping 1 m^3 of water was estimated by 0.12 L.E. (Egyptian pound) according to Abdrabbo *et al.,* (2021). The returns of each tested treatment were calculated according to Cimmyt (1988).

2.6. Statistical analysis

Data were statistically analyzed using the SAS program (SAS institute, 2006). The difference among means was considered significant at $p \leq 0.05$ referring to the LSD value according to Waller and Duncan (1969).

3. Results and Discussion

3.1. Vegetative growth characteristics

Table 3 shows the vegetative growth parameters, *i.e.*, plant height, number of leaves, total chlorophyll content as well as fresh and dry weights of plants under different irrigation levels and nitrogen forms that reveal significant differences among treatments. Results presented in Table 3

Middle East J. Agric. Res., 11(1): 89-102, 2022
EISSN: 2706-7955 ISSN: 2077-4605 *DOI: 10.36632/mejar/2022.11.1.9*

Table 3: Effect of different irrigation levels and nitrogen forms on vegetative growth parameters of eggplant during the two studied seasons.

Treatment		No. of leaves plant^{-1}		Plant height (cm)		Stem diameter (mm)		Fresh weight (g plant^{-1})		Dry weight (g plant^{-1})		Chlorophyll (SPAD)	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
50% of IR	**NO_3^-**	17.4	16.8	27.7	28.7	9.50	9.30	584	410	132	133	42.7	42.2
	NH_4^+	13.1	15.6	24.8	28.3	9.30	9.40	456	448	108	98.0	33.1	42.4
	NO_3^-+NH_4^+	17.7	19.5	31.3	32.8	9.60	10.6	616	453	120	151	41.8	41.2
75% of IR	**NO_3^-**	36.5	36.8	59.6	47.2	14.7	15.5	1102	1057	278	306	39.0	40.6
	NH_4^+	35.9	32.7	56.1	52.5	12.0	11.6	986	949	234	241	31.5	33.4
	NO_3^-+NH_4^+	35.6	38.5	62.1	70.8	15.3	15.7	1148	1211	335	288	39.6	39.0
100% of IR	**NO_3^-**	38.0	40.1	65.3	68.3	10.6	12.5	1213	1373	275	256	35.5	34.3
	NH_4^+	36.4	34.4	59.7	51.7	11.6	11.2	1056	1121	229	240	30.7	31.8
	NO_3^-+NH_4^+	39.2	39.9	75.3	77.3	12.1	12.7	1306	1334	287	283	34.5	38.1
$LSD_{0.05}$		**0.769**	**1.624**	**1.254**	**1.896**	**0.157**	**0.219**	**2.876**	**3.129**	**2.974**	**2.939**	**1.474**	**0.973**
Irrigation Mean	**50%**	16.1	17.3	27.9	29.9	9.5	9.8	552	437	120	127	39.2	41.9
	75%	36.0	36.0	59.3	56.8	14.0	14.3	1079	1072	282	278	36.7	37.7
	100%	37.9	38.1	66.8	65.8	11.4	12.1	1191	1276	264	259	33.6	34.7
$LSD_{0.05}$		**1.130**	**1.936**	**2.109**	**2.276**	**0.989**	**0.938**	**2.433**	**3.327**	**2.274**	**2.933**	**1.873**	**2.153**
Nitrogen Mean	**NO_3^-**	30.6	31.2	50.9	48.1	11.6	12.5	966	947	228	231	39.1	39.0
	NH_4^+	28.5	27.6	46.9	44.2	11.0	10.7	832	839	190	193	31.8	35.9
	NO_3^-+NH_4^+	30.8	32.6	56.3	60.3	12.4	13.0	1023	999	247	241	38.7	39.4
$LSD_{0.05}$		**0.693**	**0.828**	**1.284**	**2.725**	**0.548**	**0.328**	**3.102**	**2.998**	**2.424**	**1.990**	**0.736**	**0.574**

indicated that the highest vegetative growth characters were observed by irrigation treatment of 100% of IR followed by 75% of IR in the two seasons. There were significant reductions in plant growth properties recorded by 50% irrigation level of IR in both seasons. Generally, the results indicated that vegetative parameters increased with applying ammonium nitrate fertilizer, followed by calcium nitrate, and the lowest vegetative parameters were obtained by applying ammonium sulfate fertilizer. Regarding the interaction effect between irrigation levels and nitrogen forms on vegetative parameters, the combination between the highest irrigation level (100% of IR) combined with ammonium nitrate fertilizer had the highest vegetative growth parameters followed by 100% irrigation level of IR combined with calcium nitrate fertilizer. The lowest vegetative growth parameters were recorded when a low irrigation level was combined with ammonium sulfate fertilizer.

This might be owing to the involvement of water in the transfer of photosynthetic assimilates, resulting in increases in most vegetative growth features, or it could be related to the depressing effect of soil dryness on leaf formation and function, growth, and development. It is acknowledged that plant development is a mission of total moisture potential, which if decreased, increases the concentration of soluble salts in the soil. Furthermore, giving appropriate moisture to plants may combine to pace the physiological activities in the plant. Also, it promotes metabolism translocation, which leads to an increase in the concentration of organic molecules in plants. The obtained results are in harmony with those by Kirnak *et al.,* (2001) and El-Miniawy (2015), they mentioned that water stress reduced eggplant leaf area and negatively impacted hormonal balance, plant growth, and assimilate translocation, and that drought stress reduced eggplant height much more than control. In addition, Inalpulat *et al.,* (2014) reported that photosynthesis and chlorophyll measurements can be used as a strong indicator of water stress in eggplant, they suggested that low irrigation level or drought stress decreased plant growth due to a reduction in extension growth and increased leaf thickness. They also indicated that there were changes in leaf area due to the reduction of leaf growth, accelerated leaf senescence, and great leaf abscission by the end of the stress period. This was one of the main mechanisms by which plants adapted to declining soil water.

Nitrogen fertilization forms used in the current study affected the vegetative growth parameters of eggplant. The increments in these parameters were statistically significant especially with 100:0 NO_3^- : NH_4^+ and 50:50, compared to the other treatments in both seasons. The results coincided with those reported by Abood *et al.,* (2019) who reported that the development of eggplant was the best with applying calcium nitrate [$Ca(NO_3)_2$]. Mwinuka *et al.,* (2021) reported that solute concentration in ammonium-treated plants was lower than in plants grown with nitrate. They suggested that the growing deficit in ammonium-treated plants did not appear may be due to pH changes in the solution. The greatest plant growth occurred when NO_3^- supplied 100% of nitrogen application. The highest total dry weight was obtained with applying ammonium nitrate fertilizer, but it was not significantly different from those of calcium nitrate. Apparently, eggplant is sensitive to NH_4^+ nutrition in solution culture. Because the lowest plant growth occurred when NH_4^+ supplied 100% of the N. This reduction in plant growth of different plant parts increased with each increment in NH_4^+ form. These results agree with those obtained by Kotsiras *et al.,* (2005).

3.2. Early and total yield

Early and total fruit yields per plant under different irrigation levels and nitrogen forms showed lowest values were obtained by 50% irrigation level of IR in the two studied seasons (Table 4). Data showed that the irrigation treatment of 75% of IR produced the highest values of fruit number, early and total yield per plant followed by the irrigation level 100% of IR. Regarding the nitrogen forms, obtained data indicated that the highest yield was obtained from applying ammonium nitrate fertilizer, followed by calcium nitrate relative to those grown at the other treatments. The interaction between irrigation levels and nitrogen forms indicated that the highest early and total fruit yield of eggplant were obtained by the application of irrigation level 75% of IR combined with ammonium nitrate treatment.

However, significant reductions in yield components were recorded in plots of irrigation water that exceeded 75% of IR in both seasons. Such negative effect might be due to the influence of increasing available soil water on plant growth since the irrigation with 75% of irrigation requirements produced the highest values of plant vegetative growth characters in the two seasons resulting in increments in yield components.

Table 4: Effect of different irrigation levels and nitrogen forms on yield measurements of eggplant during the two studied seasons.

Treatment		Early yield (kg m^{-2})		Total yield (kg m^{-2})		No. of fruits $plant^{-1}$	
		2020	2021	2020	2021	2020	2021
50% of IR	**NO_3^-**	0.51	0.47	1.66	2.33	13.4	11.7
	NH_4^+	0.44	0.32	1.64	1.96	10.2	10.2
	$NO_3^-+NH_4^+$	0.75	0.55	2.06	3.31	12.5	12.7
75% of IR	**NO_3^-**	0.99	0.79	4.90	4.50	18.1	18.1
	NH_4^+	0.89	0.68	3.57	3.58	15.4	15.6
	$NO_3^-+NH_4^+$	1.10	1.19	4.49	4.66	21.6	19.2
100% of IR	**NO_3^-**	0.89	0.70	3.20	3.15	17.8	17.0
	NH_4^+	0.53	0.46	2.68	2.05	12.2	15.5
	$NO_3^-+NH_4^+$	1.04	1.02	3.70	4.03	20.8	17.9
$LSD_{0.05}$		**0.021**	**0.182**	**0.084**	**0.330**	**0.330**	**1.217**
Irrigation Mean	**50%**	0.57	0.45	1.79	2.53	12.1	11.6
	75%	0.99	0.88	4.32	4.25	18.3	17.6
	100%	0.82	0.72	3.19	3.08	16.9	16.8
$LSD_{0.05}$		**0.022**	**0.130**	**0.281**	**0.463**	0.463	**2.321**
Nitrogen Mean	**NO_3^-**	0.80	0.65	3.25	3.33	16.4	15.6
	NH_4^+	0.62	0.49	2.63	2.53	12.6	13.8
	$NO_3^-+NH_4^+$	0.96	0.92	3.42	4.00	18.3	16.6
$LSD_{0.05}$		**0.027**	**0.210**	**0.351**	**0.291**	0.291	**1.329**

Lovelli *et al.,* (2007) found the same results, stating that there were decreases in fruit output, quality, plant vegetative development, and photosynthetic activity, as well as an increase in stomatal resistance under deficit irrigation conditions. While a linear relationship was discovered between irrigation water amount and eggplant production to a certain level, increasing water did not produce a substantial increase, causing a loss in yield (Senyigit *et al.,* 2013). Water stress influenced the photosynthetic responses and yield of eggplant, according to Inalpulat *et al.,* (2014). These results are confirmed with those obtained by Ahmad (2016) and Al-Shammari *et al.,* (2020), the enhancement of total yield and the number of fruits per plant as a result of the application of the optimum amount of water level could be attributed to raising soil moisture content, which led to the reduction of soil salinity, compared to low water levels. This reduction created more optimum environmental conditions and increases the absorption by roots. This optimum environmental condition increased vegetative growth and leaf area, which increased the photosynthetic rate and lead to increased yield consequently number of fruits.

The nitrogen forms also affected the eggplant yield. The increments in these parameters were statistically significant especially with applying calcium nitrate and ammonium nitrate fertilizers, compared to ammonium nitrogen form. The results coincided with those reported by Bader *et al.,* (2020) who stated that yield of eggplant was the best with applying NO_3^--N. Reduction in fruit yield by lowering the ratio of NO_3^- to NH_4^+ within the N supply has been reported for eggplant (Al-Shammari *et al.,* 2019). The low yield under ammonium nitrogen form may be due to competition with NH_4^+ inhibiting K and other cations uptake. Potassium deficiency can cause a decrease in fruit size and failure of fruit to develop properly at the stem end. Kotsiras *et al.,* (2002) demonstrated that eggplant growth is sensitive to high concentrations of NH_4^+. However, the current study's findings indicate that the NH_4^+ ratio influences the mineral composition of the fruit. In practice, using a high NH_4^+:NO_3^- ratio results in lower yields and smaller, lesser-quality fruits.

3.3. Plant nutrient content

Nutrient content of N, P, and K percentages of eggplant leaf was influenced by irrigation level during the studied seasons (Table 5). The highest chemical constituent percentage of the eggplant leaves was recorded by the lowest irrigation level treatment (50% of IR) followed by irrigation level 75% of IR during both seasons. The highest irrigation level (100% of IR) contained the lowest nitrogen percentage of the plant leaves. Data in Table 5 revealed that nitrogen forms affected the percentage of nutrient contents significantly during both experimental seasons. The highest value occurred under $Ca(NO_3)_2$ treatment followed by NH_4NO_3 treatment. Ammonium sulfate treatment had the lowest nutrients percentages in the leaf during both seasons. According to the effect of different irrigation levels and N forms on NPK percentages in eggplant leaf, data indicated that the highest value was recorded in plants under 50% of irrigation requirement combined with $Ca(NO_3)_2$ treatment followed by irrigation level 50% of IR combined with NH_4NO_3 in both seasons. The highest irrigation level (100% of IR) combined with $(NH_4)_2SO_4$ significantly recorded the lowest NPK percentages during both successive seasons.

The supply of the appropriate ratio of the two main N forms induced a synergistic growth response that exceeded the maximum growth rate produced by the sole application of NO_3^--N in the current study. Obtained findings show that nitrogen application with an appropriate NH_4^+:NO_3^- ratio promotes the accumulation of photosynthetic materials in pepper vegetative tissues (Zhang *et al.,* 2019). Plants treated with a 50:50 NH_4^+:NO_3^- ratio, on the other hand, showed a reduced promoting effect, indicating that a high concentration of NH_4^+ could inhibit the growth of eggplant. A similar trend has been observed in other species (Zhang *et al.,* 2019). In addition, they discovered that an optimum ammonium-nitrate ratio encouraged root development in pepper, including root length, surface area, volume, and root tips. On contrary, Mwinuka *et al.,* (2021) found that plants may develop longer roots when ammonium is the predominant N source.

Table 5: Effect of different irrigation levels and nitrogen forms on nutrient contents of eggplant during the two studied seasons.

Treatment		**N (%)**		**P (%)**		**K (%)**		**NO_3^- (mg kg^{-1})**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
50% of IR	**NO_3^-**	5.02	4.48	0.69	0.74	3.42	3.39	203	276
	NH_4^+	3.58	3.90	0.68	0.56	2.94	2.81	161	164
	NO_3^-+NH_4^+	4.50	4.51	0.53	0.67	3.08	3.38	171	178
75% of IR	**NO_3^-**	4.29	4.43	0.58	0.62	2.67	2.96	170	233
	NH_4^+	3.42	3.46	0.45	0.52	2.53	2.54	122	149
	NO_3^-+NH_4^+	3.93	4.36	0.51	0.61	2.63	2.85	162	177
100% of IR	**NO_3^-**	3.37	4.02	0.49	0.54	2.61	2.87	161	139
	NH_4^+	3.18	3.09	0.39	0.50	2.10	2.14	101	104
	NO_3^-+NH_4^+	3.71	3.95	0.45	0.51	2.48	2.67	149	129
$LSD_{0.05}$		**0.143**	**0.103**	**0.018**	**0.010**	**0.122**	**0.128**	**1.272**	**1.674**
Irrigation Mean	**50%**	4.37	4.30	0.63	0.66	3.14	3.19	178	206
	75%	3.88	4.08	0.52	0.58	2.61	2.78	151	186
	100%	3.42	3.69	0.44	0.52	2.40	2.56	137	124
$LSD_{0.05}$		**0.02**	**0.19**	**0.13**	**0.07**	**0.29**	**0.22**	**3**	**2**
Nitrogen Mean	**NO_3^-**	4.23	4.31	0.59	0.63	2.90	3.07	178	216
	NH_4^+	3.39	3.48	0.51	0.53	2.53	2.50	128	139
	NO_3^-+NH_4^+	4.05	4.28	0.50	0.60	2.73	2.96	161	161
$LSD_{0.05}$		**0.326**	**0.392**	**0.097**	**0.073**	**0.208**	**0.197**	**3.012**	**2.904**

3.4. Water use efficiency (WUE)

Water use efficiency (WUE) of eggplant was decreased gradually with increasing irrigation levels (Table 6). The highest value of water use efficiency of eggplant crop was obtained by 75% irrigation level and the lowest value was obtained by irrigation level 100% of IR. Regarding the effect of nitrogen form treatments, data illustrated that there is a significant difference among tested treatments, using ammonium nitrate led to increasing WUE in both seasons, followed by calcium nitrate treatment. As to the interaction between irrigation and nitrogen fertilization treatments, the highest

WUE was obtained by irrigation level 75% of IR combined with calcium nitrate treatment. The irrigation level 100% of IR combined with ammonium sulfate treatment had the lowest WUE in both studied seasons. These results are in line with those obtained by Abdrabbo *et al.,* (2017); Badr *et al.,* (2020). Amiri *et al.,* (2012) indicated that the increase in WUE could be due to the increment in crop yield. On contrary, excessive water volume can decrease the plants' growth rate, due to oxygen deprivation in the roots. Besides, the additional water should reflect similar rate of increment in yield, due to additional costs, based on WUE. However, the type of soil should also be considered.

Table 6: Effect of different irrigation levels and nitrogen forms on water use efficiency (WUE) during the two studied seasons.

Fertilization	**NO_3^-**	**NH_4^+**	**NO_3^- +NH_4^+**	**Mean A**	**NO_3^-**	**NH_4^+**	**NO_3^- +NH_4^+**	**Mean A**
Irrigation	**First season**				**Second season**			
50% of IR	1.27	1.25	1.57	1.36	1.75	1.47	2.49	1.90
75% of IR	2.49	1.82	2.28	2.20	2.25	1.79	2.33	2.13
100% of IR	1.22	1.02	1.41	1.22	1.18	0.77	1.51	1.16
Mean B	1.66	1.36	1.75		1.73	1.34	2.11	
$LSD_{0.05}$	**Mean A**	**Mean B**	**Mean A*B**		**Mean A**	**Mean B**	**Mean A*B**	
	0.0151	**0.0328**	**0.0261**		**0.0137**	**0.0252**	**0.0330**	

3.5. Economic analysis

Operating costs of producing one acre of eggplant using three irrigation levels and different nitrogen forms were estimated including the seasonal cost such as irrigation and nitrogen fertilizer (Table 7). The cost of irrigating eggplant by 100% of IR is about 1500 EGP per acre. As for irrigation treatment 75% of IR, it was about 1200 EGP per acre, and for the irrigation treatment 50% of IR, it was about 800 EGP during the two studied seasons (Table 7). We considered irrigation cost due to the average maintenance of the irrigation network and the fuel consumption. The cost of using different forms in nitrogen fertilization was also considered in this analysis. The other costs of production were not considered such as labor, agro-inputs, irrigation, etc., because these are the same for the tested treatments on one acre of cultivating eggplant.

The results in Figure 1 show that using irrigation level 75% of IR gave the highest net income values; the irrigation level 100% of IR came at in the second order. The lowest net income was obtained by reducing the amount of irrigation water to a level of 50% of IR. Obtained data indicated that the benefits (net income) of using ammonium nitrate as nitrogen form were higher than using the other nitrogen fertilization forms, followed by calcium nitrate fertilizer. (Figure 2). Ammonium nitrate treatment with irrigation level 75% of IR were superior in net income for the two years of study, compared to the other treatments, the use of ammonium nitrate came in second order. The lowest net income values were obtained by using ammonium sulfate under irrigation at a level of 50% of IR. With respect to the relative increase in income compared to the control treatment.

From the abovementioned results we can conclude that, the use of ammonium nitrate fertilization improved the profitability of eggplant during the two seasons compared to the rest of the treatments under irrigation level 75% of IR.

Middle East J. Agric. Res., 11(1): 89-102, 2022
EISSN: 2706-7955 ISSN: 2077-4605 *DOI: 10.36632/mejar/2022.11.1.9*

Table 7: Economic analysis for using irrigation level treatments and nitrogen forms of eggplant during the two studied seasons.

Irrigation treatments	Nitrogen treatments	Yield kg m^{-2}	Yield ton $acre^{-1}$	Gross income acre	Irrigation cost L.E. $acre^{-1}$	Nitrogen cost kg $acre^{-1}$	Seasonal nitrogen cost L.E. $acre^{-1}$	other costs L.E. $acre^{-1}$	Total treatments cost L.E.	Net income L.E. $acre^{-1}$
First season (2020)										
50% of IR	NO_3^-	1.66	6.98	20937	788	258	1419	5000	2207	18730
	NH_4^+	1.64	6.90	20702	788	190	1520	5000	7308	13394
	$NO_3^-+NH_4^+$	2.06	8.66	25981	788	120	552	5000	6340	19642
75% of IR	NO_3^-	4.90	20.6	61699	1181	258	1419	5000	7600	54099
	NH_4^+	3.57	15.0	45040	1181	190	1520	5000	7701	37338
	$NO_3^-+NH_4^+$	4.49	18.8	56525	1181	120	552	5000	6733	49792
100% of IR	NO_3^-	3.20	13.4	40323	1575	258	1419	5000	7994	32329
	NH_4^+	2.68	11.2	33739	1575	190	1520	5000	8095	25644
	$NO_3^-+NH_4^+$	3.70	15.6	46679	1575	120	552	5000	7127	39552
Second season (2021)										
50% of IR	NO_3^-	2.33	9.79	29362	788	258	1419	5000	2207	27156
	NH_4^+	1.96	8.21	24641	788	190	1520	5000	7308	17333
	$NO_3^-+NH_4^+$	3.31	13.9	41711	788	120	552	5000	6340	35372
75% of IR	NO_3^-	4.50	18.9	56737	1181	258	1419	5000	7600	49137
	NH_4^+	3.58	15.1	45163	1181	190	1520	5000	7701	37461
	$NO_3^-+NH_4^+$	4.66	19.6	58723	1181	120	552	5000	6733	51989
100% of IR	NO_3^-	3.15	13.2	39683	1575	258	1419	5000	7994	31689
	NH_4^+	2.05	8.6	25839	1575	190	1520	5000	8095	17744
	$NO_3^-+NH_4^+$	4.03	16.9	50810	1575	120	552	5000	7127	43683

Average price 3 L.E. kg^{-1}
Calcium nitrate costs 5.5 L.E. kg^{-1}
Ammonium sulfate costs 8 L.E. kg^{-1}
Ammonium nitrate costs 4.6 L.E. kg^{-1}

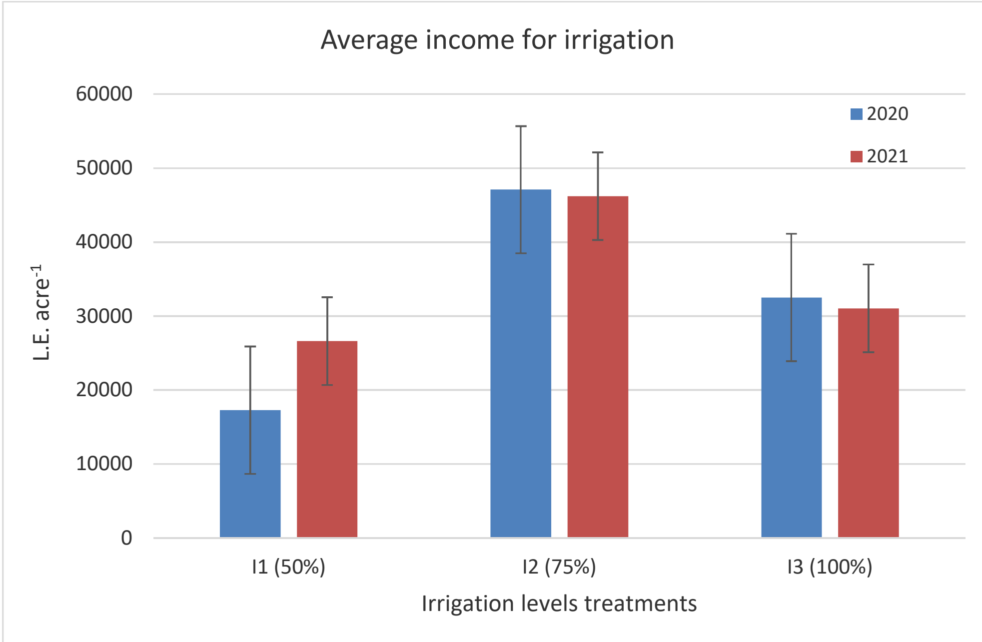

Fig. 1: Effect of irrigation level treatments on average net profit per acre during 2020/2021 seasons

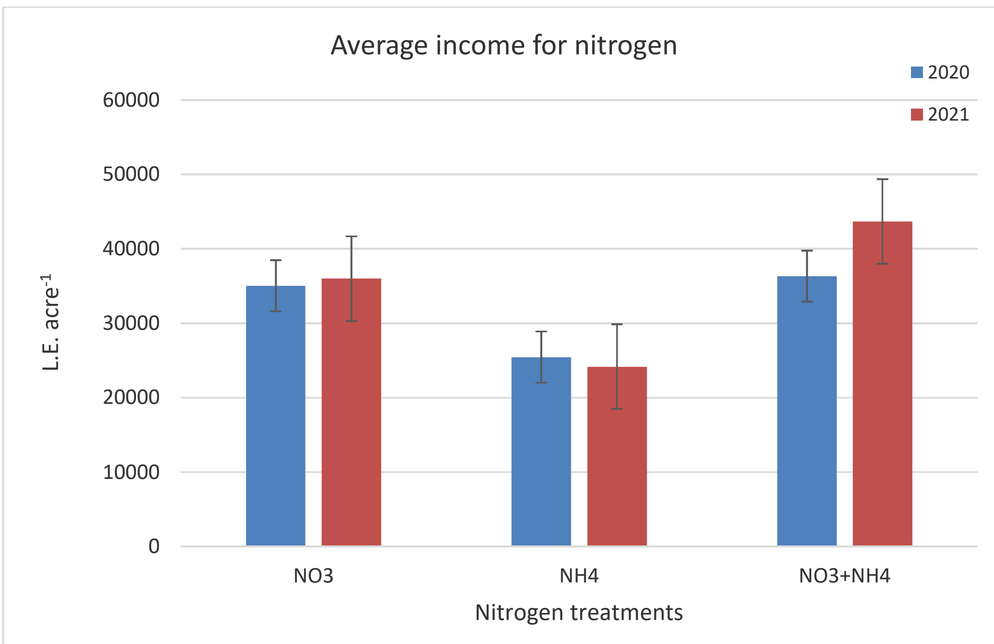

Fig. 2: Effect of nitrogen forms on average net profit per acre during 2020/2021 seasons

4. Conclusion

The previously mentioned results indicated that the application of optimum irrigation needs (75% of IR) of eggplant throughout the growing seasons increased growth characteristics (plant height, number of leaves, stem diameter, chlorophyll content as well as total fresh and dry weights) and fruit yield, which stimulated and promoted plant growth. The fertilization with NO_3^- as nitrogen form had the best growth characteristics and yield. Increasing the percentage of ammonium N resulted in a drop in fruit output. Because eggplant is sensitive to continuous NH_4^+-N nutrition, changing the NH_4^+:NO_3^- ratio boosts plant development and yield.

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