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FERTIGATION FOR IMPROVED WATER USE EFFICIENCY AND CROP YIELD

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Abstract

A greenhouse experiment was carried out at the Al-Muzahmiya Research Station, King Abdulaziz City for Science and Technology, Riyadh, to evaluate the effect of fertigation on cucumber yield. Five labelled N (^{15}N) treatments namely a control, soil application (120 mg N L^{-1}), N-1 (60 mg N L^{-1}), N-2 (120 mg N L^{-1}) and N-3 (180 mg N L^{-1}) were tried for their effect on greenhouse cucumber yield. A cucumber cultivar (Figaro F-1) was sown as test crop. The experiment was carried out during the period from April to July, 1997. The mean fresh fruit cucumber yield ranged between 7.73 to 33.74 t ha^{-1}. Highest yield was obtained with the labelled N application of 180 mg L^{-1}. The mean ranges for the different elements in the plant leaves were 1.33-2.70% (N), 0.364-0.515% (P) and 1.57-3.82% (K). Whereas, in the plant shoot these ranges were 1.26-2.42% (N), 0.28-0.49% (P) and 4.74-9.45% (K). The mean content of the different elements in the cucumber fruit was 2.15-3.70% (N), 0.47-0.73% (P) and 4.40-5.23% (K). The soil salinity varied between 2.23-4.66 dS m^{-1} in the top soil (0-20 cm depth) and 0.95-2.62 dS m^{-1} in the sub-surface (20-40 cm depth) soil. The application did not affect significantly the soil salinity and was found well below the hazardous limit for most crops. The evolution of the other elements was different.. For example, elements such as Ca, P and K showed an increase while Na showed a decrease, whereas the Mg content did not respond with increasing N application. The soil moisture ranged between 8.06-9.15% (0-20 cm depth) and 5.51-9.36% (20-40 cm depth) and did not show any effect of N application. The nitrogen use efficiency (NUE) varied between 72.70 to 129.53 kg kg^{-1} N in the different N treatments. The mean ^{15}N a.e. ranged from 0.010 to 0.844% (leaves), 0.058 to 0.855% (shoots), 0.044 to 0.747 (roots) and 0.07 to 0.823 % (fruits). In conclusion, the mean highest yield of cucumber as fresh fruit was 33.74 t ha^{-1}, obtained with 180 mg N L^{-1} relative to all other treatments. Nitrogen applied through fertigation was more effective towards yield improvement than soil application. The NUE was highest with 60 mg N L^{-1} as compared to all other higher dose of N application. The research findings showed that there is a lot of potential for adoption of fertigation practices in order to increase the production of greenhouse crops, improving the economics of these crops.

1. INTRODUCTION

The traditional application of fertilizers with advanced and improved irrigation methods has serious limitations. Modern irrigation systems such as trickles, mini-sprinklers and sprinklers, which have a higher water application efficiency, are considered more suitable for fertigation. As such, dissolved fertilizers required by the crops are directly applied through the irrigation water to the soil surrounding the active root zone of plants.

Fertigation is an effective tool to control placement, timing and the type of fertilizer needed according to the soil fertility status and the growth stage of the crop. This technology improves the fertilizer use efficiency (FUE) and minimizes nutrient losses due to volatilization, leaching and fixation in less available forms. Fertigation, if managed properly, provides potential opportunities for the growing plants with conditions similar to hydroponics. Moreover, a continuous improvement in irrigation technology and efficient use of irrigation water and fertilizers is essential to keep food supply in balance with the increasing demand on environmentally sound grounds [1]. Fertigation in Lebanon is being practiced on field orchards and greenhouse crops with both sprinkler and drip irrigation systems to increase crop production [2]. In addition to the above, in sandy, rocky and other marginal agricultural lands (calcareous soils) fertigation allows accurate control of water and nutrients which is an essential pre-requisite for rational crop production. In Cyprus and other Middle East Mediterranean countries where modern irrigation systems are already widely used, fertigation is expanding rapidly. The scarcity of water underlined the need for improvement of water use efficiency (WUE) and it has been demonstrated that fertigation with modern irrigation technology could help substantially in this respect. Because fertigation also causes reduction in soil salinity due to the intermittent use of fertilizers, the soil solution conditions are improved particularly for salt sensitive crops [3].

Although fertigation is already widely used in most countries of the region, information on nutrient and other fertilizer requirements for most vegetable crops, fruit trees, fodder and other crops is still inadequate. It has been found that poor fertigation and irrigation management techniques resulted in low average yield of protected tomato: 130 t ha^{-1} [2] versus 350 tons ha^{-1} in the case of appropriate fertigation [1]. Some research has been undertaken to evaluate the response of some vegetable crops to fertigation [4], chemigation and salinity [5,6]. Similarly, Sabra [7] reported a potato (Sponta) yield of 25 t ha^{-1} with conventional fertilizer application as compared to 40 t ha^{-1} with a modern irrigation system (sprinkler vs furrow). It was noticed that low fertilizer use efficiency (LFUE) due to the extensive fertilizer use during the last few decades coupled to the type of fertilizers used and the method of application created serious agricultural and environmental problems. The environmental impact of such fertilization becomes more pressing recently, since NO_3^--N from the irrigated areas is a potential source of soil and water pollution. The seawater has also been polluted in many countries. Pollution by fertilizers is becoming a universal problem, which needs new approaches in order to be alleviated and to be controlled over a long period of time. Therefore, fertigation is an improved way of supplying nutrients to crops thereby reducing leaching losses of N and as such avoiding groundwater pollution [8].

Fertigation is a new technology, which has been tested and further developed in some Middle East Countries. In general, fertigation has received great attention and has probably the largest application both in the developed countries and in the N.E. region [9,10,11,12,13]. The research done in Cyprus indicates that fertigation could be a break through in fertilizer-irrigation management of vegetables, fruit trees, fodder and other crops. This may lead to a very high yield of good quality on a sustainable agricultural development and environmental conservation. The results obtained through appropriate fertigation fully indicate the superiority of fertigation under irrigated conditions. The nitrogen fertilizer use efficiency (NFUE) was almost 80% and that of phosphorus (P) was above 70% at farmers' level. Furthermore, increase in yield and quality improvement of the produce showed a very high potential for this method. For example, the yield of greenhouse tomato and cucumber was around 300 and 250 t ha^{-1}, respectively as compared to the field grown potato and cucumber which was of the order of 180 and 80 t ha^{-1}, respectively, for a growing period of 120 days.

Since the application of fertilizers is becoming easy due to its higher solubility, the farmers are applying much higher doses than the crop nutrient requirements. This leads to significant leaching losses of applied nutrients, thus decreasing the fertilizer use efficiency substantially and increasing tremendously the environmental pollution hazards. Hence, irrigation as well as fertilizer application should be based on crop requirements. Therefore, research on fertigation with the ultimate goal of improving the old and new fertilizer package for different crops is gaining momentum. The main objective of this research was to develop new packages of irrigation and fertilizers in order to improve yield and quality of different crops in order to protect natural resources and the environment. Presently, the use of labelled N fertilizers coupled with the use of the neutron probe (an easy way of soil moisture measurements) can help significantly the development of this research.
The detailed objectives were:

1. to compare the conventional fertilization techniques with fertigation;
2. to study the nitrogen use efficiency under conventional nitrogen application and fertigation;
3. to evaluate potential NO_3-N pollution with the conventional method of fertilization and fertigation;
4. to transfer the technology to the farming community for overall improvement of the economy.

2. MATERIALS AND METHODS

The experiment was carried out at the Al-Muzahmiya Research Station, King Abdulaziz City for Science and Technology, Riyadh. The experiment was carried out in the greenhouse, covering an area of about 1500 m^2.

2.1. Treatments

The labelled N treatments were as follows:

1.	Control	= 0 N
2.	Soil application	= 120 mg L^{-1}
3.	N-1	= 60 mg L^{-1}
4.	N-2	= 120 mg L^{-1}
5.	N-3	= 180 mg L^{-1}

The test crop was cucumber (*Figaro F1 cultivar*). The seeds were planted on April 10, 1996 and the transplanting was done on April 21, 1996. The total area of the experiment was 45 × 30 m^2. There were three rows in each treatment. Each row was 10 m long. The distance between row to row was 1.2 m and that of plant to plant was 0.6 m. There were 16 plants in each row. The total number of plants was 1440. Labelled N was applied only to 180 plants according to the experimental design. The concentration of ^{15}N was 5% and diluted to 83% to meet the required concentration for the plants. The crop was first harvested on June 23, 1996 and the second harvest was done on July 12, 1996.

In the case of soil application (N_s), the N was applied according to the practices followed by the local farmers. The total amount of N fertilizer applied in N-2 through the irrigation system (fertigation) was equivalent to the N applied under soil application. The amount of N fertilizer for the soil application was the amount normally recommended to farmers for a particular crop, but applied by the conventional method of fertilization.

2.2. Methodology for application of labelled ^{15}N

2.2.1. Soil Application

The labelled fertilizer was applied to the soil at the time of planting in the central row, at a distance, which was irrigated with three or five drippers. For this treatment, the total amount of N could be applied as a basal dose at the time of planting or as a split application according to the existing practices in each country.

2.2.2. Fertigation

The labelled fertilizer-N was applied through inverted bottles with a dripper at the cup of each bottle. The bottom of each bottle was cut. At the place where the inverted bottles applied the ^{15}N fertilizer, the irrigation line was without drippers. As such, all the plants were irrigated and fertilized through the irrigation system except those fertigated with ^{15}N. The amount of water and labelled-N applied through the inverted bottles was equivalent to that applied through the single dripper.

However, P and K were applied uniformly through the irrigation system. The irrigation-fertigation system was composed of two injectors (fertilizer applicators), five main lines of plastic tubing in which the five nitrogen (N) rates were injected. There were one to five lateral lines for each crop. The drippers were spaced laterally according to the distance of planting. Each fertilizer injector served to supply all treatments with a uniform concentration of P and K and to produce the N levels for the three fertigation treatments. The N fertilizer was injected by the second injector at a ratio of 1:2:3 in the irrigation system for the N-1, N-2 and N-3 treatments, respectively.

2.2.3. Experimental Design

The experiment was laid out by following The Randomized Complete Block Design and the treatments were replicated six times.

3. RESULTS AND DISCUSSION

3.1. Fruit Yield

Depending on different N treatments, the mean fruit yield ranged between 7.73 to 33.74 t ha^{-1} (Table I). The yield increased significantly above the control by increasing the N application ($LSD_{0.05}$ = 4.625). The increase in yield was significant among all N treatments except for the soil application and the N-1 treatment where it was not significant. The results indicate that application of higher doses of N improved the fruit yield considerably as compared to the control treatment. It also infers that higher doses of N were more effective in increasing the fruit yield than the equivalent amount of N applied as soil application.

3.2. Mineral composition of the plant leaves, shoots and fruits

3.2.1. Nitrogen

Leaf samples — The mean N content of the cucumber leaves varied between 1.33 to 2.70% for the various N treatments (Table I). The percent nitrogen in the plant leaves increased significantly with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 0.486). The difference in N content was not significant between the soil and the control treatment. Although there was an increasing trend in the N content of the leaves with increasing N application, the difference in %N was not significant among the N-1, N-2 and N-3 treatments.

Shoot samples — The mean N content varied from 1.26 % to 2.42% for the various N treatments (Table I, Appendix II). The N content increased significantly with the increase in N application ($LSD_{0.05}$ = 0.596). The difference in %N was not significant between the control, the soil application, the N-1 and N-2 as well as between the N-2 and N-3 treatments. The significant increase in N content of the shoots at higher doses of N indicates the higher availability of N in the soil solution in the vicinity of the plant roots thereby increasing the chances for the plants to absorb more N.

TABLE I. EFFECT OF N FERTILIZER ON YIELD AND MINERAL COMPOSITION OF CUCUMBER

Treatment	Yield kg/plot	Leaf N	Leaf P	Leaf K	Shoot N	Shoot P	Shoot K	Fruit N	Fruit P	Fruit K
		%								
Control	7.73 d	1.60b	0.48a	1.57b	1.45b	0.42ab	4.74b	3.70	0.73	4.40
Soil	15.90 c	1.33b	0.48a	1.96b	1.26b	0.49a	4.94b	2.64	0.65	5.11
N-1	14.17 c	2.36a	0.52a	3.50a	1.61b	0.45a	7.77a	2.15	0.49	5.23
N-2	20.74 b	2.64a	0.43ab	3.82a	2.23a	0.36ab	9.45a	2.60	0.47	5.15
N-3	33.74 a	2.70a	0.36b	3.26a	2.42a	0.28b	7.37a	2.87	0.61	4.94

The figures in one column followed by the same letter are not significantly different at $LSD_{0.05}$.

3.2.2. Phosphorus

Leaf samples — The mean P content varied between 0.364% to 0.515% for the various N treatments (Table 1, Appendix I). The %P decreased significantly with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 0.109). The difference in P content was not significant among the control, the soil application, the N-1 and N-2 as well as between the N-2 and N-3 treatments. An inverse relationship was found between the N and P content in the plant leaves.

Shoot samples — The mean P content ranged between 0.28% to 0.49% for the various N treatments (Table I, Appendix II). There was a significant decrease in P content with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 0.151). The difference in P content was not significant among the control, the soil application, the N-1 and N-2 as well as the N-2 and N-3 treatments. It was found that N and P contents are inversely related.

3.2.3. *Potassium*

Leaf samples — Depending on the different N treatments, the mean K content ranged between 1.57% to 3.82% (Table I, Appendix I). The K content increased significantly with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 0.837). There was no significant difference in K content between the control and soil treatment as well as between the N-1, N-2 and N-3 treatments. The results showed a positive relationship between the increase in N application and the corresponding higher contents of K in plant leaves ($R^2 = 0.734$).

Shoot samples — The mean content of K varied between 4.74% and 9.45% for the various N treatments (Table I, Appendix II). The amount of K increased with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 2.092). There was no significant difference in K content between the control and the soil treatment as well as among the N-1, N-2 and N-3 treatments. The analyses of data indicate that the increase in N application enhanced the uptake of K by the plants. This might be due to the healthy growth of the plants receiving higher doses of N fertilizer as compared to the treatments receiving low doses of N fertilizer.

3.2.4. *Mineral composition of the fruit*

The mean N, P and K content of the cucumber fruit varied respectively between 2.15% to 3.70%, between 0.47% to 0.73%, and between 4.40 % to 5.23 % for the various N treatments (Table I).

3.3. Effect of N application on soil properties

3.3.1. *Electrical conductivity (EC) of the soil*

The mean EC of the soil, expressed as dS m^{-1}, varied between 2.23 to 4.66 in the top soil (0–20 cm depth) for the different N treatments (Table II, Appendix III). The EC increased significantly with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 2.082). There was no significant difference among the control, the soil treatment, the N-1 and N-2 as well as among the control, the N-1, N-2 and N-3 treatments. The soil salinity did not increase to harmful limits. Most of the vegetable crops are sensitive only at germination stage.

The mean EC of the soil ranged from 0.95 to 2.62 dS m^{-1} in the subsurface (20–40 cm depth) soil for the various N treatments (Table II, Appendix III). The EC increased significantly with the increase in N application as compared to the control treatment ($LSD_{0.05}$ = 1.65). There was no significant difference in soil salinity among the control, the soil and N-1 treatment as well as among the control, the N-1, N-2 and N-3 treatments. Overall, it was found that the EC of the soil was relatively lower in the subsurface than in the surface soil. This also suggests that the amount of irrigation water applied was not enough to leach excess soil salinity from the 0–20 cm zone of the soil, which is considered as the most active root zone.

3.3.2. *Calcium*

The mean content of calcium in the soil varied from 237.5 mg L^{-1} to 571.5 mg L^{-1} in the top soil (0–20 cm depth) for the various N treatments (Table II, Appendix IV). The Ca content increased significantly with increasing N application as compared to the control treatment ($LSD_{0,05}$ = 175.18). The difference in Ca contents was significant between the N-3 and all other N treatments. However, there was no significant difference in Ca content among the control, the soil application and the N-1 and N-2 treatments.

The mean Ca content in the top soil (20–40 cm depth) ranged between 122.7 mg L^{-1} and 314.0 mg L^{-1} for the various treatments (Table II, Appendix IV). There was a significant increase in Ca content with increasing N application as compared to the control treatment ($LSD_{0.05}$ = 104.55). The Ca content was significantly higher in the N-3 treatment than in all other N treatments, whereas no significant difference was found among the control, the soil application and the N-1 and N-2 treatments. It was also noticed that the Ca content was higher in the top soil than in the subsurface soil. The higher Ca content in the top soil could be due to the higher water uptake by the plants.

TABLE II. EFFECT OF N FERTILIZER ON THE SALINITY (EC_e) AND MINERAL COMPOSITION (mg L^{-1})OF THE SOIL

Treatment	EC_e dS m^{-1}		Ca		Mg		Na	
	1	2	1	2	1	2	1	2
Control	2.96ab	1.52ab	237.5b	122.6b	79.96a	31.63bc	148.0a	101.6a
Soil	2.23b	0.95b	257.8b	153.5b	50.70a	22.83c	110.0a	66.6a
N-1	3.33ab	1.91ab	354.1b	195.8b	77.86a	38.80bc	133.3a	99.2a
N-2	3.01ab	2.16a	350.7b	197.0b	61.45a	40.16b	77.5a	75.3a
N-3	4.66a	2.62a	571.5a	314.0a	88.30a	63.83a	85.8a	93.3a

Treatment	K		P		Soil Moisture (%)	
	1	2	1	2	1	2
Control	90.0b	57.5b	32.7c	34.4a	9.15a	7.75a
Soil	91.7b	63.0b	35.8bc	30.1a	8.91a	8.36a
N-1	282.5a	198.3a	45.2ab	35.9a	8.70a	5.51a
N-2	239.2ab	177.4a	44.6a	30.9a	8.77a	9.36a
N-3	286.7a	202.5a	52.3a	36.1a	8.06a	6.26a

The figures in one column followed by the same letter are not significantly different at $LSD_{0.05}$.
1. Means for the top soil (0–20cm depth) 2. Means subsurface soil (20–40 cm depth)

3.3.3. *Magnesium*

The mean content of Mg varied between 50.70 mg L^{-1} and 88.30 mg L^{-1} for the different N treatments (Table II, Appendix IV).

There was no significant increase of the Mg content in the top soil (0–20 cm depth) with increasing application of N as compared to the control treatment ($LSD_{0.05}$ = 38.55). Also, there was no significant difference in Mg content among all N treatments.

The mean content of Mg in the top soil (20–40 cm depth) ranged between 31.63 mg L^{-1} to 63.83 mg L^{-1} for the different N treatments (Table II, Appendix IV). There was a significant increase in Mg content with increasing N application as compared to the control treatment ($LSD_{0.05}$ = 15.47). There was no significant difference in Mg content among the control, the soil application and the N-1 treatment, as well as among the control, and the N-1 and N-2 treatments. However, the difference in Mg content was significant between the N-3 treatment and all other N treatments.

3.3.4. Sodium

The mean Na content in the top soil (0–20 cm depth) ranged between 77.5 mg L^{-1} and 148.0 mg L^{-1} for the different N treatments (Table II, Appendix V). Though there was a decreasing trend in the Na content of the soil with the increasing N application, but the difference in Na content was not significant among the different N treatments ($LSD_{0.05}$ = 72.92).

The mean Na content of the subsurface soil (20–40 cm depth) ranged between 75.3 mg L^{-1} to 101.6 mg L^{-1} for the various N treatments (Table IV). There was no significant difference in Na content among the different N treatments ($LSD_{0.05}$ = 47.74). This was further indicated by the poor value of the correlation coefficient (R^2) being only 0.323 for the top soil and 0.305 for the subsurface soil.

3.3.5. Potassium

The mean K content of the soil ranged between 90.0 mg L^{-1} to 286.7 mg L^{-1} in the top soil (0–20 cm depth) for the various N treatments (Table II, Appendix V). The K content increased significantly with the increasing N application as compared to the control treatment ($LSD_{0.05}$ = 154.85). The difference in K content was not significant among the control, the soil application and the N-2 treatment, as well as among the N-1, N-2 and N-3 treatments. The results suggest that a higher application of N enhanced the availability of K in the soil.

The mean K content in the subsurface soil (20–40 cm depth) ranged between 57.50 mg L^{-1} to 202.50 mg l^{-1} for the various N treatments (Table II, Appendix V). There was a significant increase in K content with the increasing N application as compared to the control treatment ($LSD_{0.05}$ = 72.72). The difference in K content was not significant between the control and the soil application as well as among the N-1, N-2 and N-3 treatments.

3.3.6. Phosphorus

The mean content of P in the top soil (0–20 cm depth) ranged between 32.66 to 52.32 mg L^{-1} for the various N treatments (Table II, Appendix VI). The P content increased significantly with the increasing N application as compared to the control treatment ($LSD_{0.05}$ = 10.329). The difference in P content was not significant between the control and the soil application, between the soil application and the N-1 treatment, as well as among the N-1, N-2 and N-3 treatments. The results indicate that a higher dose of N fertilizer significantly increased the P content of the soil.

The mean content of P in the subsurface soil (20–40 cm depth) ranged between 30.1 mg L^{-1} to 36.1 mg L^{-1} for the various N treatments (Table II Appendix VI). There was no significant increase in the P content with an increasing N application ($LSD_{0.05}$ = 12.64).

3.3.7. Soil moisture content

The mean moisture content of the topsoil (0–20 cm depth) varied between 8.06% to 9.15% for the different N treatments (Table II, Appendix VII). The application of N did not show any significant effect on the moisture content of the soil ($LSD_{0.05}$ = 2.908).

The mean moisture content of the subsurface soil (20–40 cm depth) varied between 5.51% to 9.36% for the different N treatments (Table II, Appendix VII). The difference in soil moisture was not significant among all N treatments ($LSD_{0.05}$ = 3.588).

3.4. Nitrogen use efficiency (NUE)

The mean nitrogen use efficiency (NUE) based on fresh fruit yield was 72.70 kg kg^{-1} N for the soil application, 129.53 kg kg^{-1} N for the N-1, 94.74 kg kg^{-1} N for the N-2 and 102.82 kg kg^{-1} N for the N-3 treatment (Table III). The NUE was significantly higher in the N-1 treatment than in all other N treatments. However, the difference in NUE was not significant between the N-2 and N-3 treatments. It was observed that the NUE significantly decreased with increasing N application. This could be due to the excessive vegetative growth of the plants receiving a higher N dose. It could be safely to conclude that the N application at a rate of 60 mg L^{-1} of irrigation water proved to be the optimum dose for normal crop yield as compared to higher doses of N application.

3.5. Recovery of ^{15}N by the plants

Leaves — The mean range of the ^{15}N content in the plant leaves was from 0.010 to 0.844% for the different treatments (Table IV). The content of labelled nitrogen increased with an increase in N application as compared to the control treatment ($LSD_{0.05}$ = 0.110). The difference in amount of labelled N was significant among all treatments except for the N-2 and N-3 treatment where it was not significant.

Shoots — The mean range of the labelled N content varied between 0.058 to 0.855% for the different treatments (Table IV). The content of ^{15}N increased with increasing N application as compared to the control treatment ($LSD_{0.05}$ = 0.119). The difference in labelled N content was not significant between the control and the soil application as well as between the N-2 and N-3 treatment.

Roots — The mean labelled nitrogen ranged between 0.044 to 0.738% for the different N treatments (Table IV). The content of labelled N increased with increasing N application among all treatments except for the N-2 and N-3 treatments where it was not significant ($LSD_{0.05}$ = 0.080).

The mean range of the non-labelled N content ranged between 0.92 to 1.97% for the different treatments (Table IV). The content of N increased with an increasing N application as compared to the control treatment ($LSD_{0.05}$ = 0.769). The difference in N content was not significant between the control, the soil application and the N-1 treatment; and between the N-1 and N-2 treatment as well as between the N-2 and N-3 treatment.

Fruit — The mean range of the labelled N varied from 0.007 to 0.823% for the different treatments (Table IV). The results showed an increase in N content with the increasing N application as compared to the control treatment.

TABLE III. EFFECT OF FERTIGATION ON NITROGEN USE EFFICIENCY (NUE) OF CUCUMBER (kg FRESH FRUIT kg^{-1} N)

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
Soil	81.28	57.78	71.13	80.64	73.01	72.70	72.70 c
N-1	99.02	114.29	104.14	142.26	172.71	144.73	129.53 a
N-2	82.56	76.85	78.08	83.15	141.16	106.65	94.74 b
N-3	93.13	82.10	70.28	95.02	148.78	127.60	102.82 b

Values in the mean column followed by the same letter are not significantly different by $LSD_{0.05}$).

TABLE IV. EFFECT OF FERTIGATION ON NITROGEN RECOVERY BY THE PLANTS (%)

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
a. Leaves: ^{15}N a.e.							
Control	0.026	0.010	0.005	0.001	0.006	***	0.010 d
Soil	0.125	0.192	0.162	0.006	0.229	0.030	0.124 c
N-1	0.376	0.705	0.385	0.301	0.533	0.675	0.495 b
N-2	***	0.840	0.836	0.506	0.830	0.764	0.755 a
N-3	0.854	0.812	0.843	0.859	0.855	0.841	0.844 a
b. Shoots ^{15}N a.e.							
Control	0.062	0.044	0.077	***	0.015	0.094	0.058 c
Soil	0.108	0.152	0.148	0.006	0.160	0.251	0.137 c
N-1	0.357	0.725	0.345	0.307	0.509	0.758	0.500 b
N-2	0.848	0.813	0.841	0.538	0.847	0.801	0.781 a
N-3	0.859	0.844	0.854	0.860	0.867	0.845	0.855 a
c. Roots: ^{15}N a.e.							
Control	0.022	0.085	0.054	0.010	0.058	0.035	0.044 d
Soil	0.121	0.192	0.173	0.008	0.315	0.035	0.141 c
N-1	0.446	0.579	0.462	0.458	0.557	0.654	0.526 b
N-2	0.746	0.818	0.788	0.610	0.773	***	0.747 a
N-3	0.801	0.731	0.740	***	0.776	0.642	0.738 a
d. Roots % N							
Control	0.98	0.61	0.63	1.50	0.93	0.89	0.92 c
Soil	0.84	0.85	0.79	1.52	0.92	0.96	0.98 c
N-1	1.20	1.09	1.30	1.04	1.16	1.72	1.25 bc
N-2	1.75	2.42	2.00	1.65	2.01	***	1.97 ab
N-3	2.96	1.45	1.72	***	2.27	1.20	1.92 a
a. Fruit: ^{15}N a.e.							
Control	***	***	***	0.007	***	***	0.007
Soil	***	***	***	0.020	***	0.034	0.027
N-1	0.581	0.553	0.601	0.351	0.645	0.630	0.560
N-2	0.798	0.806	0.657	0.580	0.772	0.785	0.733
N-3	0.826	0.798	0.820	0.824	0.840	0.827	0.823

4. CONCLUSIONS AND RECOMMENDATIONS

The mean fresh fruit yield ranged between 7.73 to 33.74 t ha^{-1} for the different N treatments. The highest yield of fresh cucumber was obtained with an application rate of 180 mg N L^{-1}. The concentration of various nutrients such as N, P and K showed a significant increase with increasing N application. The N application did not show any significant effect on the soil salinity. It was found that the Ca, P and K content increased while the Na content decreased with increasing N application. However, the Mg uptake did not respond to the N application. Similarly, the soil moisture content did not show any significant change with the N application. The nitrogen use efficiency (NUE) ranged between 72.70 to 129.53 kg kg^{-1} N for the different N treatments. The recovery of ^{15}N increased significantly with increasing N application.

In conclusion, the highest mean yield (33.74 t ha^{-1}) of fresh cucumber was obtained with an application rate of 180 mg N L^{-1}. The results showed that there is a lot of potential for adoption of fertigation practices to increase greenhouse productions in Saudi Arabia.

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APPENDIX I. EFFECT OF FERTIGATION ON FRUIT YIELD OF CUCUMBER (t ha^{-1})

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
Control	8.33	5.83	5.00	6.11	12.64	8.47	7.73 d
Soil	17.78	12.64	15.56	17.64	15.97	15.83	15.90 c
N-1	19.83	12.50	11.39	15.56	18.89	15.83	14.17 c
N-2	18.06	16.81	17.08	18.19	30.97	23.33	20.74 b
N-3	30.56	26.94	23.06	31.18	48.82	41.87	33.74 a

The values in the mean column followed by the same letter are not significantly different by $LSD_{0.05}$.

APPENDIX II. EFFECT OF FERTIGATION ON THE NPK CONTENT OF THE LEAVES (%)

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
a. Nitrogen (N)							
Control	1.31	1.06	1.76	2.50	1.37	1.60	1.60
Soil	1.07	1.38	0.99	2.45	0.70	1.41	1.33
N-1	2.54	2.29	2.94	2.38	2.06	1.96	2.36
N-2	2.64	2.60	2.98	2.51	2.72	2.40	2.64
N-3	2.98	2.84	2.21	2.73	2.42	3.00	2.70
b. Phosphorus (P)							
Control	0.60	0.53	0.52	0.24	0.51	0.48	0.48
Soil	0.41	0.69	0.47	0.43	0.39	0.51	0.48
N-1	0.67	0.62	0.45	0.44	0.36	0.55	0.52
N-2	0.43	0.48	0.44	0.42	0.51	0.28	.43
N-3	0.45	0.41	0.24	0.32	0.33	0.43	0.36
c. Potassium (K)							
Control	1.39	1.60	2.34	1.21	1.29	1.56	1.57
Soil	3.36	1.42	1.49	1.80	1.76	1.90	1.95
N-1	2.74	2.68	3.40	3.59	3.43	5.15	3.49
N-2	3.82	3.60	4.40	2.70	5.08	3.30	3.82
N-3	3.31	2.47	3.20	2.86	4.17	3.57	3.26

APPENDIX III. EFFECT OF FERTIGATION ON THE NPK CONTENT OF THE SHOOTS (%)

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
a.Nitrogen (N)							
Control	1.32	0.69	1.11	3.02	1.28	1.31	1.45
Soil	0.91	1.23	1.16	2.31	0.78	1.17	1.26
N-1	2.22	1.19	1.60	1.61	1.40	1.66	1.61
N-2	2.39	2.62	2.58	1.71	2.23	1.83	2.23
N-3	2.72	1.90	2.54	2.43	2.43	2.50	2.42
b. Phosphorus (P)							
Control	0.55	0.47	0.43	0.23	0.60	0.26	0.42
Soil	0.66	0.56	0.62	0.25	0.61	0.26	0.49
N-1	0.54	0.36	0.63	0.45	0.32	0.40	0.45
N-2	0.48	0.35	0.35	0.22	0.40	0.36	0.36
N-3	0.14	0.32	0.26	0.24	0.25	0.47	0.28
c. Potassium (K)							
Control	4.79	4.19	3.04	4.55	5.25	6.64	4.74
Soil	4.69	3.75	4.13	6.22	4.66	6.21	4.94
N-1	7.15	7.36	7.77	7.77	8.27	8.30	7.77
N-2	14.4	7.54	7.62	8.31	9.44	9.45	9.45
N-3	3.38	6.52	9.58	8.79	8.09	7.86	7.37

APPENDIX IV. EFFECT OF FERTIGATION ON THE SOIL SALINITY (EC_e) AS dS m^{-1}

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
0–20 cm depth							
Control	2.9	0.8	4.6	2.0	1.8	5.6	2.9
Soil	2.0	1.7	3.5	1.4	3.8	1.0	2.2
N-1	3.9	7.0	1.4	2.5	3.0	2.2	3.3
N-2	4.9	2.1	1.9	2.0	5.3	1.9	3.0
N-3	5.1	4.3	5.4	5.7	5.8	1.7	4.7
20–40 cm depth							
Control	1.5	0.7	2.1	2.0	1.0	1.8	1.5
Soil	1.0	0.6	0.9	1.4	1.0	0.8	0.9
N-1	1.1	3.5	1.5	1.1	2.6	1.7	1.9
N-2	3.0	1.8	1.7	2.3	2.9	1.3	2.2
N-3	1.0	2.3	4.5	3.9	2.6	1.4	2.6

APPENDIX V. EFFECT OF FERTIGATION ON THE Ca AND Mg CONTENT OF THE SOIL (mg L^{-1})

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
Calcium (Ca)			**0–20 cm depth**				
Control	237	68	461	180	241	238	238
Soil	244	18	401	221	401	100	258
N-1	465	567	170	261	381	281	354
N-2	561	260	200	180	682	221	351
N-3	571	581	682	662	702	241	571
			20–40 cm depth				
Control	28	46	200	141	100	221	123
Soil	100	40	401	200	80	100	154
N-1	82	301	90	281	261	160	196
N-2	197	164	200	281	200	140	197
N-3	260	261	461	401	321	180	314
Magnesium (Mg)			**0–20 cm depth**				
Control	80	52	143	57	42	106	80
Soil	66	65	43	37	81	13	51
N-1	95	159	47	37	77	52	78
N-2	95	41	51	47	90	45	61
N-3	119	75	83	93	101	59	88
			20–40 cm depth				
Control	22	23	53	26	39	28	31
Soil	28	12	23	29	23	22	23
N-1	26	63	25	42	47	30	39
N-2	40	37	34	53	42	35	40
N-3	68	48	88	84	49	46	64

APPENDIX VI. EFFECT OF FERTIGATION ON THE Na AND K CONTENT OF THE SOIL ($mg\ L^{-1}$)

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
Sodium (Na)			**0–20 cm depth**				
Control	148	60	215	130	115	220	148
Soil	65	85	165	90	185	70	110
N-1	60	290	65	120	190	75	133
N-2	105	70	60	100	60	78	
N-3	105	80	120	20	145	45	86
			20–40 cm depth				
Control	50	55	180	85	75	165	102
Soil	50	40	70	80	95	65	67
N-1	50	145	70	130	145	55	99
N-2	92	70	55	110	75	50	75
N-3	80	65	155	125	95	40	93
Potassium (K)			**0–20 cm depth**				
Control	90	30	150	100	50	120	90
Soil	35	100	160	65	155	35	92
N-1	235	715	45	310	160	230	283
N-2	320	195	190	225	325	180	239
N-3	325	185	335	385	355	135	287
			20–40 cm depth				
Control	75	70	85	20	50	45	58
Soil	50	63	70	60	70	65	63
N-1	150	355	160	210	95	220	198
N-2	177	197	150	125	275	140	177
N-3	235	120	275	245	210	130	203

APPENDIX VII. EFFECT OF FERTIGATION ON THE P CONTENT OF THE SOIL ($mg\ L^{-1}$)

Treatment	R-1	R-2	R-3	R-4	R-5	R-6	Mean
Phosphorus (P)			**0–20 cm depth**				
Control	33	46	34	26	32	26	33
Soil	41	49	33	28	30	33	36
N-1	55	47	59	39	32	40	45
N-2	66	60	43	53	36	40	45
N-3	88	57	46	46	36	42	52
			20–40 cm depth				
Control	31	44	25	58	24	24	34
Soil	35	36	27	35	17	29	30
N-1	30	36	37	64	27	22	36
N-2	31	30	50	21	20	33	31
N-3	40	23	55	51	22	26	36

APPENDIX VIII. EFFECT OF FERTIGATION ON THE SOIL MOISTURE CONTENT (%)

Treatment	R-1	R-2	R-3	R-4	R-5	Mean
0–20 cm depth						
Control	8.86	12.14	6.32	13.05	8.02	9.15
Soil	10.00	8.13	7.22	13.17	6.04	8.91
N-1	7.96	8.88	10.75	9.93	6.01	8.70
N-2	10.60	8.23	7.93	14.75	2.34	8.77
N-3	6.80	9.59	10.78	8.36	4.79	8.06
20–40 cm depth						
Control	7.02	9.16	6.32	10.18	6.09	7.75
Soil	8.50	6.90	8.67	9.62	8.14	8.36
N-1	6.37	5.81	6.10	5.17	4.11	5.51
N-2	5.68	5.88	9.68	8.83	16.72	9.36
N-3	6.72	9.59	5.64	5.17	4.16	6.26