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Water balance and fertigation for crop improvement in West Asia

Results of a technical co-operation project organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

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FOREWORD

Mediterranean countries have a severe shortage of water resources for agricultural, municipal and industrial purposes. This situation is aggravated daily due to the rapidly increasing population in the area. Agriculture is the biggest consumer of water with about 80% of the renewable resource used for irrigation. Traditional irrigation methods are highly inefficient: only about one-third of the applied water is actually transpired by the crops. Clearly, there is great scope for improved irrigation management.

Intensification of agricultural production to meet growing market demand requires the simultaneous application of irrigation water and fertilizers. Application of fertilizer in drip irrigation (fertigation) is an effective way to promote efficient use of these scarce and expensive resources. There is widespread interest in Mediterranean countries in fertigation. Nevertheless, information on the form and concentration of the nutrients required for different crops is presently inadequate. Moreover, the low fertilizer recoveries due to extensive fertilization practiced during the last few decades have created serious agricultural and environmental problems. High nitrate concentrations in groundwater and deterioration of some important quality parameters of agricultural products are the main concerns.

Recognizing the potential role of nuclear techniques in identifying improved water and fertilizer management practices, the IAEA implemented two regional technical co-operation projects during the period 1995–2000 with eight participating countries from the West Asia region: The Islamic Republic of Iran, Jordan, Lebanon, Saudi Arabia, the Syria Arab Republic, Turkey, United Arab Emirates and Yemen. The main objective was to establish water balance and fertigation practices using nuclear techniques, with a view to improving crop production in arid and semi-arid zones. The projects aimed to compare the following parameters under conventional fertilizer and water management practices with fertigation:

- Crop yields
- N fertilizer recovery
- Water use efficiency and crop water requirements
- Nitrate leaching.

Water use and N-fertilizer efficiency under drip irrigation compared with conventional agricultural practices were estimated using neutron probe and ^{15}N recovery techniques, respectively.

The IAEA would like to thank the participating national institutions for their commitment to the two Regional Technical Co-operation Projects, on Water Balance and Fertigation for Crop Improvement (1995–1998), and on Fertigation for Improved Water Use Efficiency and Crop Yield (1999–2000). The IAEA officers responsible for this publication were P. Moutonnet of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, and S. Chaudhri and A. Habjouqa of the Department of Technical Co-operation, as well as O. van Cleemput, L.K.Heng and P.M. Chalk.

CONTENTS

SUMMARY AND CONCLUSIONS

Two IAEA Regional Technical Co-operation Projects were implemented from 1995 to 2000 in eight countries from the West Asia region to improve the productivity of annual crops and enhance resource use efficiency in arid and semi-arid environments. The objectives were to compare crop yields, N-fertilizer recovery by crops, nitrate leaching and water use efficiency/crop water requirements under conventional fertilization/irrigation methods with fertigation. At least four sets of experimental data were collected for each of the countries involved. Crops included tomato, pepper, potato, cotton, lettuce, garlic and cucumber.

The efficacy of drip irrigation and fertigation in the region compared with conventional practices was clearly demonstrated using the neutron moisture probe to monitor soil water status and hence estimate water use efficiency, and by using ^{15}N-labelled fertilizers to estimate N use efficiency by crops. Specifically, it was shown that:

- 30 to 50% of irrigation water can be saved under drip irrigation compared with conventional irrigation practices without sacrificing crop yield or quality.
- N-fertiliser application (as well as P and K inputs in most cases) was necessary for maintaining the productivity of the irrigated crops investigated. Crop yields were up to 80% lower on zero N compared with N fertilized treatments, the response to N depending on the original soil fertility level.
- The conventional application of N-fertiliser to the soil itself (pre-planting plus split applications later on) was ineffective whatever the mode of irrigation employed, even if drip irrigation itself gave higher yields compared with conventional techniques.
- Under fertigation at increasing rates of N-fertiliser, the optimal crop yield was often reached at 50 % of the locally recommended N rate under conventional irrigation, thus resulting in considerable saving of costly fertilizer N while at the same time reducing the potential pollution hazard.

Several tangible benefits accrued from this regional TC project. It was successful in promoting the fertigation technology in eight Member States of the West Asia region through 'on-farm' and 'on-station' demonstrations in the field and greenhouse over several seasons. In addition, other modes of technology transfer such as training workshops, fellowship training, scientific visits and expert missions were undertaken. Indeed, the outputs of this Project together with other national efforts have produced a major outcome in the Mediterranean region through positively influencing Government policies on the rational use of scarce water resources for agriculture, as documented in the proceedings of the International Fertigation Workshop organized by the World Phosphate Institute (IMPHOS) and published by ICARDA (2000). In addition, the project fulfilled other important needs as highlighted in the seminal review on Advances in Fertigation by Bar-Yosef (1999, Adv. Agron. **65** 1–77). It has contributed to the efficient utilization of available equipment through provision of data on optimum consumption rates of essential nutrients by important crops as a function of time, thus adding significantly to the very limited database representing different climatic and soil conditions. The use of the soil moisture neutron probe to monitor soil water status and ^{15}N labelled fertilizers to estimate crop recovery were essential tools in obtaining vital information which added a new dimension to the data previously available.

Several strategies to further advance fertigation technologies were identified. During the 2001–2002 biennium, a new Regional TC Project for Europe was implemented in nine Member States including both annual and perennial crops. The objectives of this Project are similar to those of the previous West Asia pojects, but in future years more attention needs to be given to the application of phosphatic fertilizers through fertigation, particularly on coarse textured calcareous soils. For perennial crops grown on poorly buffered soils, due attention will need to be paid to the long-term acidifying effects of nitrogenous fertilizers and phosphoric acid applied through fertigation. There may also be considerable scope, as proposed by Bar-Yosef (1999), to either select crop species or genotypes with root architecture better suited to the confined wetting pattern afforded by drip irrigation, or alternatively, to design drip fertigation systems based on planning parameters that include root characteristics as well as soil hydraulic properties. The use of ^{15}N foliar labelling techniques to determine the distribution of belowground biomass would be an essential tool in evaluating the efficacy of either approach. A further need identified by Bar-Yosef (1999) is to develop fertigation management models based on knowledge of nutrient uptake by roots, distribution in soil and leaching outside the soil root volume. Finally, an essential component of any fertigation system is a cost-benefit analysis that not only includes economic variables but also the environmental costs associated with poor nutrient and water management.

FIELD EVALUATION OF UREA FERTILIZER AND WATER USE EFFICIENCY BY TOMATO UNDER TRICKLE FERTIGATION AND FURROW IRRIGATION IN THE ISLAMIC REPUBLIC OF IRAN

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Abstract

Urea fertilizer and water use efficiency by tomato (Early Urbana VF) were studied in a sandy loam soil, comparing trickle fertigation and conventional furrow irrigation — band fertilization systems. During the period of 1995–1998, a conventional treatment, NS, with band application of 50, 150 and 100 kg N as urea, P as diammomium phosphate and K as potassium sulfate respectively was carried out. The average concentration of N in the total irrigation water was 0, 38, 76 and 114 mg/L for the N0, N1, N2 and N3 fertigation treatments, respectively. All fertigation treatments also received equally 24 and 16 mg/L P and K, respectively. An increase of K for the conventional treatment to 1200 kg/ha in 1998 coincided with the increase of the same element to 190 mg/L for the trickle irrigated treatments. To evaluate the urea-N use efficiency, the plants of isotope subplots received 2% ^{15}N a.e. urea. The soil moisture in all treatments was measured by the neutron moisture gauge. During the first 3 years of experimentation there was no significant difference between the yields of the treatments. For the years 1995 through 1997 the average tomato yield was low in comparison to the yield shown in most reports. The yield variance among treatments and years was negligible. The highest fruit yield, 27.3 t/ha for the N1 treatment was observed in 1997. In this experiment, the low yield and urea-N use efficiency can be primarily attributed to unbalanced applied fertilizers in the trickle irrigation system. The highest urea-N use efficiency was 12.3% for the fertigation N1 treatment in 1997. In the 1998, a repetition of the experiment with increasing K rates for all treatments at the same experimental site, led to a considerable increase in yield and urea-N use efficiency as compared to previous years. The tomato fresh fruit yield attained for N0, N1, N2, N3 and NS respectively 84, 76, 69, 36 and 26 t/ha. Based on the 14N/15N ratio analysis of the dry matter the urea-N use efficiency was 42, 25, 11 and 6 for the N1, N2, N3, and NS treatments, respectively. All N treatments under trickle irrigation and conventional furrow irrigation received on average a total amount of 6,536 and 12,286 m3/ha irrigation water (1996–1998). The total water use efficiency for the NS treatment was the lowest (24 kg/ha.cm) of all treatments and was the highest for the fertigation treatment N1 (51 kg/ha.cm) (1996 – 1997). The yield increase of the fertigation treatments enhanced the water use efficiency for 1998 as compared to 1996 and 1997. The overall water use efficiency was the lowest for the NS treatment (33.3 kg/ha.cm) and the highest for urea-N0 treatment (155.4 kg/ha.cm) and urea-N1 treatment (154.1 kg/ha.cm) for 1998. This investigation indicates that application of conventional quantities of fertilizers via trickle irrigation is not suitable. In the second phase (1999–2000) of this project, with the application of proper amounts and proportions of fertilizers plus microelements, it is expected to obtain better results.

1. INTRODUCTION

Sustainable high yield with high yielding crops depends entirely on the sustainable use of the limited sources of water and energy, specifically in developing countries with arid and semi-arid regions. This can only be attained with efficient use of water and fertilizers. Any increase in N use efficiency will increase the importance of N as crop production factor, increase farmers' profit, conserve energy and raw materials required to produce fertilizer N, and minimize any adverse effects on the environment resulting from inefficient N use [1].

Fertigation as an attractive technology in modern irrigated agriculture increases yield and fertilizer use efficiency [2]. It has been reported that with fertigation, N fertilizer use efficiency can be enhanced to 80–90% [2]. Through fertigation, water and nutrients are applied to the root zone of the crop, where they are mostly needed, normally resulting in a better water and fertilizer use efficiency than with conventional irrigation and fertilization methods. Furrow irrigation and broadcast or in-band fertilization is very common by farmers in Iran. Some research has been carried out on the application of fertigation of fruit trees with drip irrigation in Iran. Research need to be done on fertigation including row crops.

Four field experiments were conducted between 1995 and 1998 with the following objectives:

(i) comparison of urea fertilizer use efficiency between conventional in-band N application and fertigation with different concentrations of urea using the 15N methodology;

(ii) comparison of water consumption and water use efficiency by tomato under trickle irrigation and conventional furrow irrigation using the neutron scattering method; and

(iii) study of the response of tomato yield to different concentrations of urea fertigation and conventional in-band application.

2. MATERIALS AND METHODS

This study was conducted from 1995 till 1998 at the Nuclear Research Center for Agriculture and Medicine in Rajaie — Shahr, Karaj, about 60 km west of Tehran. The Center is located at an altitude of 1310 m, latitude 36N, longitude 51E, with an average of 250 mm annual rainfall and 13.6°C air temperature. The experimental site was situated at the foot steps of the Alborz mountains. The experimental field was on a sandy loam soil, which had been exposed to heavy soil erosion due to the rainfall of many years. Some physical and chemical characteristics of the experimental field and irrigation water are summarized in Tables I and II.

TABLE I. SELECTED CHARACTERISTICS OF THE SOIL AT THE EXPERIMENTAL SITE

Sand (%)	Silt (%)	Clay (%)	Total N (%)	O.M. (%)	P µg/g	K µg/g	E.C. dS/m	NO_3^--N µg/g
68	15	17	0.04	0.35	5.7	160	0.53	8.7

TABLE II. CHEMICAL CHARACTERISTICS OF IRRIGATED WATER

E.C. dS/m	pH	Ca meq/L	Mg meq/L	HCO3- meq/L	SO4 meq/L	Cl meq/L	Na meq/L	NO3- ppm	NH4 ppm
1.26	7.3	4.9	2.3	4.7	6.5	2.3	6	7	0.7

The following five treatments were replicated four times in a randomized complete block design:

1. Urea-N0= 0 mg N L^{-1} trickle fertigation
2. Urea-N1= 38 mg N L^{-1} trickle fertigation
3. Urea-N2= 76 mg N L^{-1} trickle fertigation (equivalent NS treatment)
4. Urea-N3= 114 mg N L^{-1} trickle fertigation
5. Urea-NS= 500 kg N ha^{-1} conventional fertilization/furrow irrigation.

In the second half of May of each year (1995–1998) tomato (Early Urbana VF) seedlings were planted in plots consisting of five and six rows for trickle and furrow irrigation, respectively. The distance between the rows was 100 cm. The experimental layout is shown in Fig l.

2. 1. Irrigation schedule and moisture monitoring

In the trickle irrigated plots, drippers (one for each plant) were installed 50 cm apart from each other. The dripper discharge was 4 L/h. The rate of water applied was calculated on the basis of the evaporation rate from class A pan [2]. The amount of water was uniformly applied to all fertigation treatments. The furrow irrigated plots were irrigated according to the amounts that were recommended by the Ministry of Agriculture for this region [3]. Access tubes for neutron probe reading in all treatments were installed in duplicate to a depth of 100 cm below the drippers in the middle of the second row. Readings with the neutron gauge were taken before and after each irrigation at 30, 45, 60, 75 and 90 cm soil depth. Water consumption (ET) was calculated using the water balance approach [4]. Water use efficiency was calculated on the basis of the ratio of fruit — canopy dry matter weight to the amount of water consumed (Table VII and VIII).

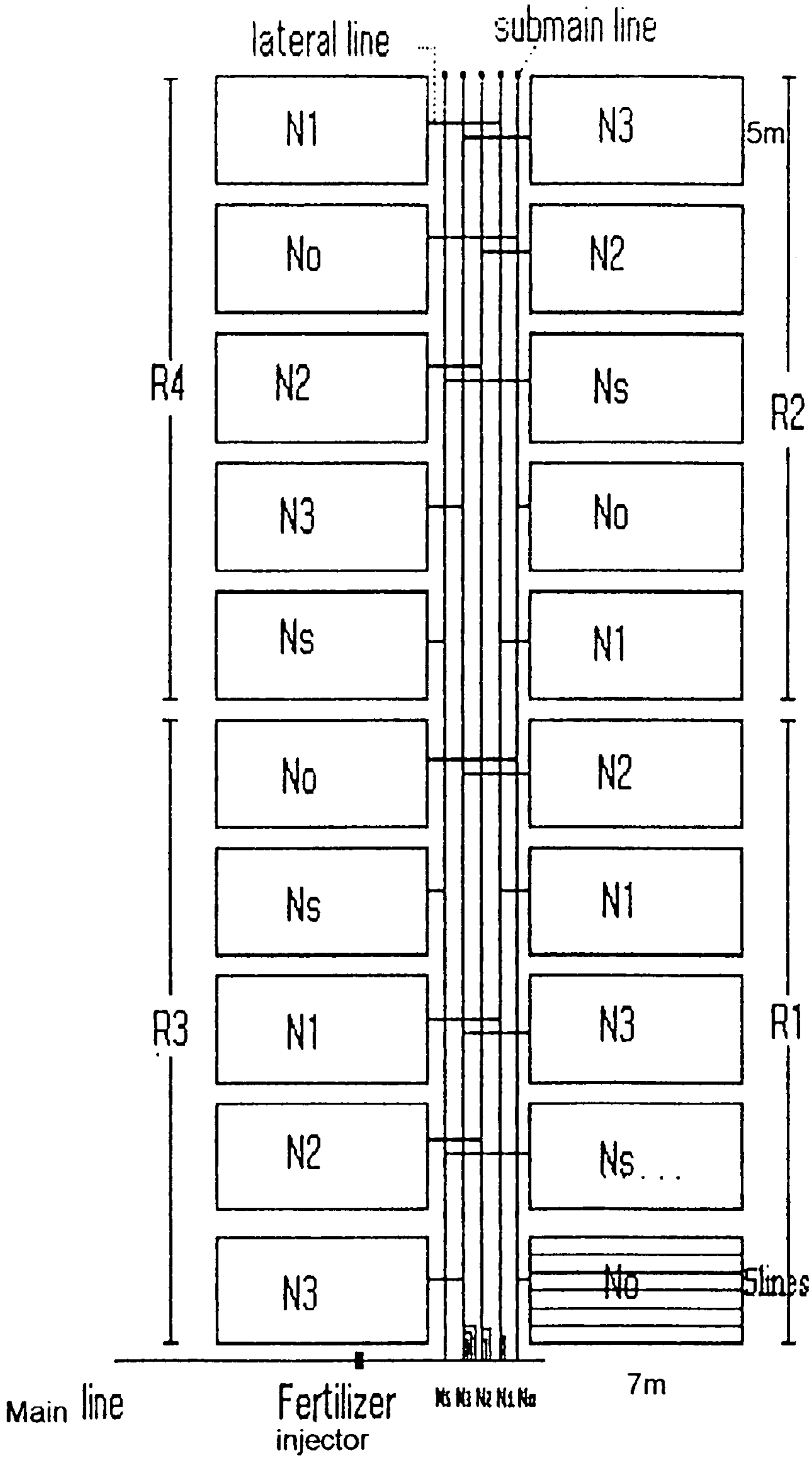

Fig 1. Experimental layout Karaj 1995–1998.

2.2. Fertilizer applications

For the 1995–1997 experiments, the amounts and forms of fertilizers used was in accordance with the recommendations for the region. The conventional NS treatment received 500 kg N/ha as urea in three stages (planting, flowering and fruiting) plus 345 kg/ha P_20_5 as diammonium phosphate at planting and flowering, and 125 kg/ha K_20 as potassium sulfate at planting in band application. Six plants from the middle of each plot received 2% ^{15}N a.e. urea as isotope subplot.

On the trickle irrigated plots, the above-mentioned fertilizers were applied through the irrigation system by the use of two fertigators: one for the application of urea and the other one for the application of diammonium phosphate and potassium sulfate. Installed microtubes in the system [5] splitted the urea in three concentrations of 38, 76 and 114 mg N/L, respectively. Phosphorus and potassium were applied to all fertigation treatments at the concentration of 24 and 16 mg/L respectively. Six drippers in the middle row of each plot were blocked and the plants received 2% ^{15}N a.e. urea through bottles. The amount of water and fertilizers applied through the bottles was equivalent to the concentrations applied through a single dripper. In the 1998, the experiment was replicated by increasing the potassium level to 1200 kg/ha for the NS treatment and 190 mg/L for all fertigation treatments. All other manipulations were the same as in the previous years.

2.3. Sampling and analysis

During the experiment the mature fruit was harvested five times. Unripe fruit and the canopy were harvested at the end of the experiment. The collected samples from yield and isotope sub-plots were weighted, and the samples from the isotope sub-plot were dried at 70°C for 48 hours. Samples were ground to pass a 0.2 mm sieve. The total N analysis was done by the micro-Kjeldahl method and the ^{15}N abundance was measured by emission spectrometry [6].

3. RESULTS AND DISCUSSION

The effect of the conventional furrow irrigation — band fertilization and trickle fertigation method with different N concentrations of urea on the tomato fresh fruit and canopy yield for three years (1995, 1996 and 1997) is presented in Table III. Statistically significant differences in fresh fruit and canopy yield from the different treatments were not observed. However, in 1997, the fruit and total yield (fruit plus canopy) produced with the N1 and N2 treatments showed a positively significant difference as compared to the other treatments. The tomato fruit yield was equivalent to 27 t/ha for each of the N1 and N2 treatments. For unknown reasons, the fruit yield (15.9 t/ha) and total fresh yield (20.6 t/ha) from the NS treatment was lower as compared to the yield obtained during previous years.

The results from three years of experimentation indicate that the average fruit yield from the NS treatment (19.3 t/ha) was lower than the average fruit yield of 36.9 t/ha for the Tehran Province and the average fruit yield of 27.3 t/ha for the whole country. This difference might be related to the chemo-physical properties of the experimental site in addition to climatic variations among these sites.

The increased yield with the fertigation method in 1997, as compared to the previous years, could be because of a more uniform water distribution in that year resulting in an improved distribution of the fertilizer. Nonetheless, as Table III shows, the fruit (the highest yield of 27.3 t/ha belonging to the N1 treatment in 1997) and canopy yield in all three years were much lower than what is reported by other investigators [2,8]. The low yield in all fertigation treatments, being the basis of this research can primarily be due to the inappropriate balance between N and K. Anyhow, the considerably low yield with the fertigation method in 1996 and 1997 has an effect on the urea-N water use efficiency hence limiting any possible interpretation.

TABLE III. FRESH FRUIT, CANOPY AND TOTAL YIELD OF TOMATO (t/ha) FOR THE 1995, 1996 AND 1997 EXPERIMENTS

Treatments	1995			1996			1997		
	Fruit	Canopy	Total	Fruit	Canopy	Total	Fruit	Canopy	Total
Urea-N0	17.6a	5.2	22.8	14.9a	5.5	20.5	21.5b	4.2	25.7
Urea-N1	20.8a	5.6	26.4	20.5a	6.0	26.4	27.3a	7.3	34.6
Urea-N2	19.2a	7.3	26.5	20.3a	6.4	26.7	27.1a	6.4	33.5
Urea-N3	22.4a	5.6	28.0	18.1a	5.9	24.0	19.5b	6.9	26.4
Urea-NS	20.8a	5.2	26.0	22.3a	5.1	27.4	15.9c	4.7	20.6

Values in columns followed by the same letter are not significantly different at the 5% probability level.

TABLE IV. FRUIT, CANOPY, AND TOTAL DRY MATTER YIELD AND UREA-N UTILIZATION OF TOMATO IN 1996

Treatment	D.M. yield t/ha	Total N %	N yield kg/ha	Nddf %	F.N.Y. kg/ha	N.U.E. %
			Fruit			
N0	0.9a	3.14	28.3	-	-	-
N1	1.2a	3.69	44.3	34.9	15.5	6.2a
N2	1.2a	3.74	44.9	35.9	16.1	3.2ab
N3	1.3a	3.86	50.2	39.2	19.7	2.6b
NS	1.4a	3.22	45.1	25.5	11.5	2.3b
			Canopy			
N0	1.3a	2.27	29.5	-	-	-
N1	1.4a	2.44	34.2	30.1	10.3	4.1a
N2	1.5a	2.41	36.2	35.9	13.0	2.6b
N3	1.2a	2.70	32.4	48.9	15.8	2.1b
NS	1.3a	2.38	30.9	32.9	10.2	2.0b
			Total			
N0	2.2a	2.71	57.8	-	-	-
N1	2.6a	3.07	78.5	32.5	25.8	10.3a
N2	2.7a	3.08	81.1	35.9	29.1	5.8b
N3	2.5a	3.28	82.6	44.1	35.5	4.7b
NS	2.7a	2.80	76.0	29.2	21.7	4.3b

Values in columns followed by the same letter are not significantly different at the 5% probability level.

The tomato fruit and canopy dry matter yields (D.M.Y.) and urea-N utilization for 1996 and 1997 (data for 1995 are not shown) are given in Tables IV and V, respectively. Based on the 1996 and 1997 results, neither the fresh nor dry matter yield showed a significant difference. The fertigation N3 treatment with 3.86% for the fruit and 2.7% for the canopy in 1996 and the fertigation N2 treatment with 3.33% for the fruit dry matter in 1997 showed the highest total N as compared to the other treatments. The N percentages for total fruit and canopy dry matter were the highest for the N3 treatment with values equivalent to 3.28 and 3.04 for 1996 and 1997, respectively. The N0 treatment produced the lowest total N percentage (fruit and canopy) in all treatments.

The highest N uptake values (N yield kg/ha) were found with the N3 and N2 treatments. They were 50.2 kg N/ha and 53.3 kg N/ha for 1996 and 1997, respectively. The lowest N uptake was found with the N0 treatment being 28.3 and 32.2 kg-N/ha for 1996 and 1997, respectively. In 1996, the N uptake by the fruit for the NS and N2 treatments, which received an equal amount of N, was not statistically different. In 1997, for unknown reasons, the NS treatment gave the lowest N yield in comparison to other treatments. This low yield was statistically significant.

TABLE V. FRUIT, CANOPY, AND TOTAL DRY MATTER YIELD AND UREA-N UTILIZATION OF TOMATO IN 1997

Treatment	D.M. yield t/ha	Total N %	N yield kg/ha	Nddf %	F.N.Y. kg/ha	N.U.E. %
			Fruit			
N0	1.3a	2.48	32.2	-	-	-
N1	1.6a	2.93	46.9	37.3	17.5	7.0a
N2	1.6a	3.33	53.3	39.4	21.0	4.2b
N3	1.4a	3.29	46.1	44.1	20.3	2.7b
NS	1.0a	3.29	32.9	27.2	8.9	1.8c
			Canopy			
N0	1.0b	1.68	16.8	-	-	-
N1	1.7a	2.29	38.9	34.2	13.3	5.3a
N2	1.5a	2.43	36.5	38.8	14.2	2.8b
N3	1.4a	2.79	39.1	51.7	20.2	2.7b
NS	1.2b	2.46	29.5	33.2	9.8	2.0c
			Total			
N0	2.3b	2.08	49.0	-	-	-
N1	3.3a	2.61	85.8	35.7	30.8	12.3a
N2	3.1a	2.88	89.8	39.1	35.2	7.0b
N3	2.8a	3.04	85.2	47.9	40.5	5.4b
NS	2.2b	2.88	62.4	30.2	18.7	3.8c

Values in columns followed by the same letter are not significantly different the 5% probability level.

The results obtained on the basis of the $^{15}N/^{14}N$ ratio analysis of the dry matter of the plant samples indicate that the %Ndff in fruit and canopy increased with increasing urea-N concentration (Tables IV and V). A higher N contribution was found from urea in all 1997 treatments as compared to the 1996 treatments. In 1997, the fertigation N3 treatment led to an uptake of 44.1 and 51.7% respectively in the fruit and canopy. Comparison between the N2 and NS treatments shows a slightly higher N uptake from urea in the N2 treatment than in the NS treatment, in both 1996 and 1997. However, this difference was not statistically significant.

The fertilizer N yield (F.N.Y. kg/ha) followed the same pattern as the %Ndff (Tables IV and V). An increase in N concentration caused an enhancement of the N taken up from the fertigation treatments. These values were higher for all treatments in 1997 than in 1996. Comparing the N uptake for the N2 and NS treatments, it was found that the fruit and canopy had a higher uptake for the N2 treatment than for the NS treatment. It was respectively 21 and 14.2 kg/ha for fruit and canopy for the N2 treatment while it was 8.9 and 9.8 kg N/ha for the NS treatment. These data refer to 1997.

The urea-N use efficiency (%N.U.E) for fruit, canopy and total are shown for 1996 and 1997 in Tables IV and V. A decrease in % N.U.E. for fruit and canopy were observed with increasing amounts of urea-N. The values showed a slight increase in 1997 relative to 1996, for all treatments. The N1 treatment produced the highest %N.U.E. for fruit and canopy in 1997 with values of 7 and 5.3%. This was statistically different from the other treatments. The urea-N use efficiency for total fruit and canopy was 12.3, 7.0, 5.4, 3.8% for respectively the N1, N2, N3 and NS treatments. The lowest N.U.E. was found for the NS treatment as compared with the N2 and the other fertigation treatments. This was statistically different. Papadopoulos [2] reports 80–90% N.U.E. in case of appropriate fertigation.

The low yield and N.U.E. for the 3-year experiment can be primarily attributed to low amounts of N and K fertilizers with an improper ratio between N and K. This inadequacy can be related to the proportions of nutrients in fertilizers used in conventional tomato cultivation. The theoretical basis for low application of K for conventional tomato cultivation has been based on the existence of a high reserve of K in Iranian soils [7]. However, this K is most likely not available to the crop when it is required. More over, the use of secondary nutrients and micronutrients is not at all popular in the conventional cultivation procedure. As a result, it is impossible to reach an optimum yield as compared with the fertigation method.

Bar-Yosef and Sagev [8] applied 1,090 kg N/ha with a ratio of 10(N): 0.9(P): 14(K) along with micronutrients and without microelements for which they found a production of 112 t/ha and 76 t/ha tomato fruit, respectively. Papadopoulos [2] reported an appropriate concentration (150–180, 30–50, 200–250 g m^{-3} of N-P-K) in the irrigation water for tomato fertigation. In another report [9] he points out that K absorption by tomato is equivalent to 1600 kg/ha. Burt et. al [10] reports that the required range of K varies from 700–1,100 kg/ha. The same authors report that, for healthy plants, the ratio of N/P is approximately 10 and N/K is approximately 1. Considering the results of the 3-year experiment and other reports indicating the requirement of more N and K for tomato fertigation in the experimental field, we feel determined to perform an investigation based on previous investigations in 1998.

The comparative results obtained from four years (1995–1998) are presented in the Figs. 2, 3, 4, 5, 6 and 7. As it is shown in Fig. 2, a fresh fruit yield of 84, 77, 69, 36 and 26 t/ha and a total fresh yield of 95, 98, 89, 50 and 35 t/ha were obtained for the N0, N1, N2, N3 and NS treatments respectively, in 1998. The fresh fruit yield of the N2 treatment was 2.5 times more than that of NS treatment. The total dry matter yield shows the same pattern, being equivalent to 9, 9, 8, 5 and 3 t/ha for the respective treatments (Fig. 3).

The total N percentage of the dry matter for the respective treatments was 2.5, 2.7, 2.8 and 2.6. However, it was not statistically different between the N2 and NS treatment. The N percentage of the fruit dry matter was higher than of the canopy. The N taken up (N-yield kg/ha) by the total dry matter for the respective treatments was 224, 243, 223, 138 and 86 kg/ha. The value for N2 was 2.5 times higher than for NS.

The % N derived from the urea fertilizer (Ndff), based on the $^{14}N/^{15}N$ ratio in the dry matter, indicates a slightly higher N uptake from urea in the fruit than in the canopy, (Fig. 4, 5). The Ndff was 43, 54, 63, and 37 for N1, N2 N3 and NS, respectively. This share of urea-N is 1.5 times more for N2 than for NS. There is an indication of increasing %Ndff in the fertigation treatments along with the increasing N input.

The N use efficiencies (%N.U.E) were 42, 25, 11 and 6 for the N1, N2, N3 and NS treatments, respectively (Fig. 7). The N.U.E in the N2 treatment was more than four times higher than in the NS treatment. This indicates that the increasing amount of K not only caused an increase in yield but also enhanced the N.U.E. for the fertigation treatments in 1998 as compared to the previous years. As already pointed out, appropriate fertigation regimes, adjusted to the soil fertility, can enhance the fertilizer use efficiency, particularly that of N, up to 80–90%. Evidently the amount of water allocation should be based on the actual crop water requirements [2].

All N treatments under trickle irrigation received a total amount of 6,879 and 6,450 m^3/ha of irrigation water for respectively 1996 and 1997 (Table VI). Otherwise, under conventional furrow irrigation the amount of irrigation water applied was 10,928 and 12,250 m^3/ha for 1996 and 1997, respectively. As it is shown in Table VII the highest water consumption (ET) was 1,041 mm and 994mm with the conventional furrow irrigation treatment (NS) for 1996 and 1997, respectively. Comparing the N2 and NS treatments (both received the same amount of urea-N), N2 consumed on average 621 mm while NS consumed 1,017 mm of water (Table VI).

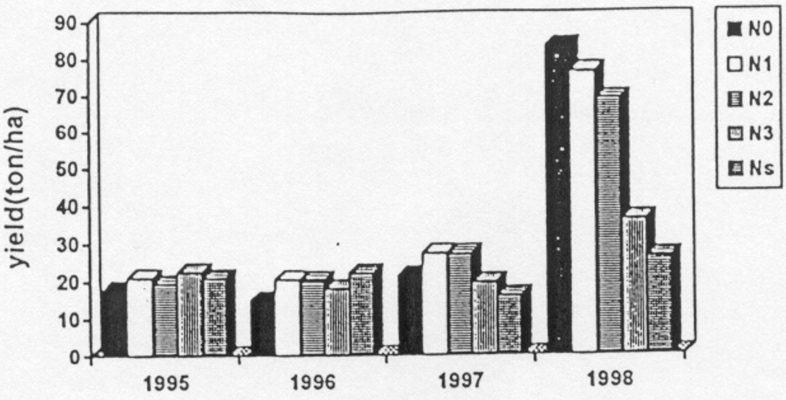

Fig.2. tomato fresh fruit weight

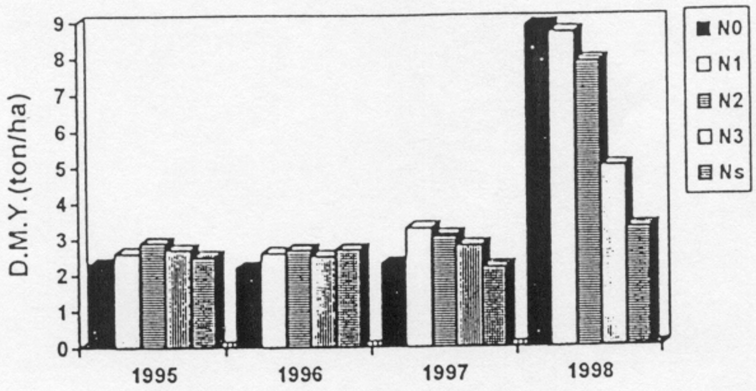

Fig.3. tomato total dry matter yield

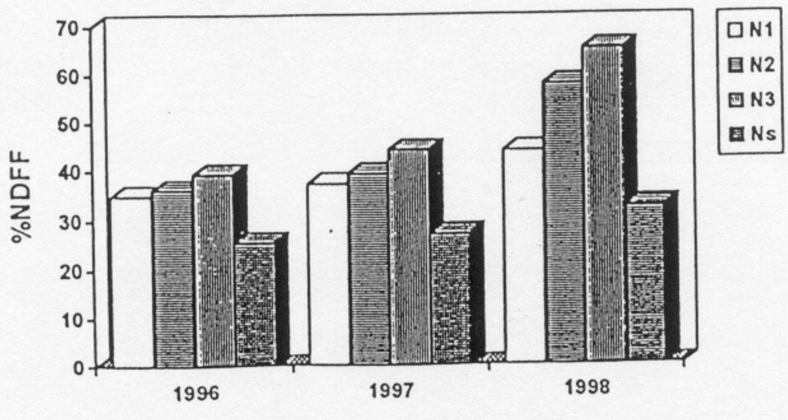

Fig.4. %NDFF for tomato fruit

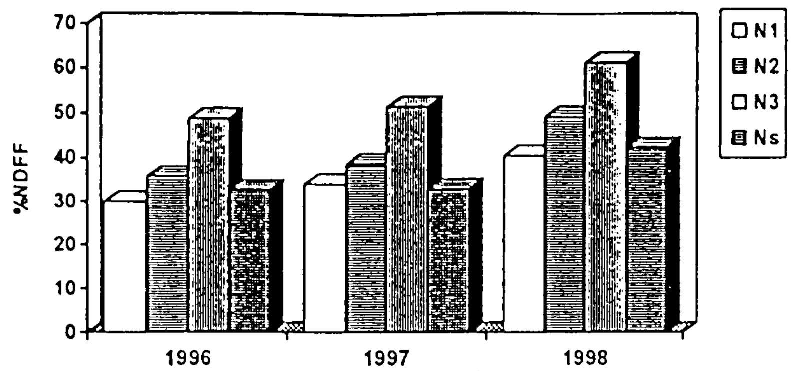

Fig.5. %NDFF for tomato canopy

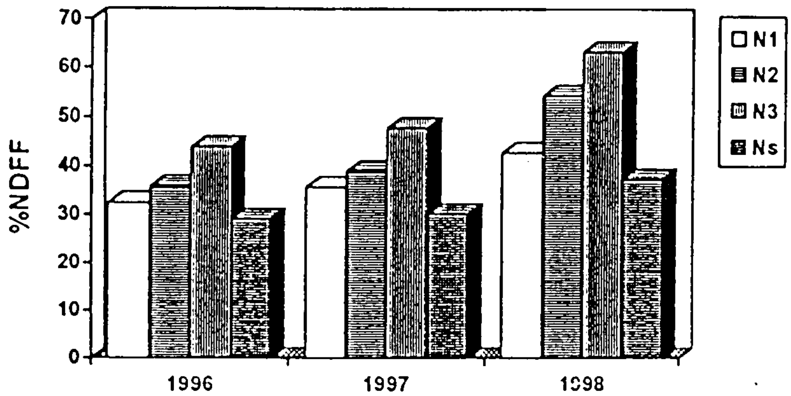

Fig.6. %NDFF for tomato total yeild

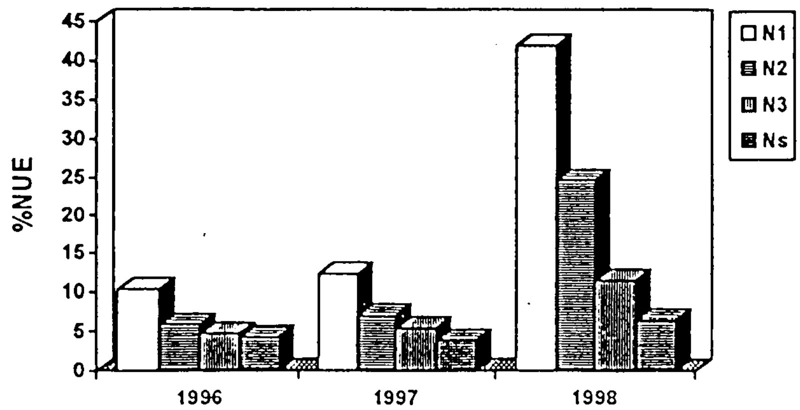

Fig.7. %NUE for tomato total yield

As it is shown in Table VII the mean total water use efficiency (1996–1997) was the lowest for the conventional furrow irrigation (24 kg/ha. cm). It was the highest for the N1 treatment (51 kg/ha.cm). In these two years the water use efficiency was low due to a general drop of yield in all treatments. Comparing N2 and NS the former, with 47 kg/ha. cm mean total water use efficiency proved to be superior to the latter treatment, with a mean total water use efficiency of 24 kg/ha.cm (Table VII).

The 1998 trickle irrigation treatments received 6281 m^3/ha water (Table VI), while the furrow irrigation treatment received 13,680 m^3/ha. From Table VIII it is clear that the fertigation led to an increased yield, indicating an enhanced water use efficiency. The total water use efficiency in the NS treatment was the lowest (33.3 kg/ha.cm), while the highest was found for the N0 and N1 treatments, respectively 155.4 kg/ha.cm and 154.1 kg/ha.cm. Comparing the N2 and NS treatments, the former with a total water use efficiency of 137.8 kg/ha.cm was superior to the latter with 33.3 kg/ha.cm (Table VIII).

TABLE VI. IRRIGATION WATER APPLIED ACCORDING TO CLASS A PAN AND RAINFALL FOR 1996–1997

Month	1996		1997		1998	
	Irrigation water (mm)	Rainfall (mm)	Irrigation water (mm)	Rainfall (mm)	Irrigation water (mm)	Rainfall (mm)
May	19.7	4	23.2	6	32.1	25.1
June	150.9	4	142	6.6	129.5	0
July	239.6	0.5	220	0.2	212.9	0.2
August	216.1	0	205.3	0	202.7	15
September	63.4	0	54.5	0	50.9	4.9
Total	687.9	8.5	645	12.8	628.1	45.2

TABLE VII. EFFECT OF IRRIGATION METHOD AND N RATES ON EVAPOTRANSPIRATION (ET) AND WATER USE EFFICIENCY (WUE) ACCORDING TO NEUTRON PROBE CALCULATION FOR TOMATO IN 1996–1997

Treatments	ET (cm)		WUE (kg/ha.cm)					
	1996	1997	1996			1997		
			Fruit	Canopy	Total	Fruit	Canopy	Total
Urea N0	65.4	52.9	13.8	19.9	33.6	24.6	18.9	43.5
Urea N1	64.1	54.0	18.7	21.8	40.6	29.6	31.5	61.1
Urea N2	64.8	59.4	18.5	23.1	41.7	26.9	25.2	52.1
Urea N3	65.7	61.8	19.8	18.3	38.1	22.6	22.6	45.2
Urea NS	104.1	99.4	13.4	12.5	25.9	10.0	12.1	22.1

TABLE VIII. EFFECT OF IRRIGATION METHOD AND N RATES ON EVAPOTRANSPIRATION (ET) AND WATER USE EFFICIENCY (WUE) ACCORDING TO NEUTRON PROBE CALCULATION FOR TOMATO IN 1998

Treatments	ET (cm)	WUE (kg/ha.cm)		
		Fruit	Canopy	Total
Urea-N0	57	90.3	65.1	155.4
Urea-N1	56.2	87.2	66.9	154.1
Urea-N2	57.3	75.0	62.8	137.8
Urea-N3	58.4	42.5	42.8	85.3
Urea-NS	98.5	16.7	16.6	33.3

4. CONCLUSION

An increased nutrient use efficiency and quality and quantity of crop production depends on the adequate and appropriate amount of macro and microelements with fertigation. Obviously, if this principal is not precisely followed, it will lead to a lower efficiency (trickle irrigation), lower quality and quantity of harvested product, lower fertilizer use efficiency and risk for environmental contamination. However, more technical assistance and local research is needed to obtain better results at the farm level.

ACKNOWLEDGEMENT

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NITROGEN AND WATER UTILIZATION BY TRICKLE FERTIGATED GARLIC USING THE NEUTRON GAUGE AND ^{15}N TECHNOLOGIES

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Abstract

The objective of this study was to increase water and fertilizer use efficiency for conventional fertilization and fertigation. The following treatments were included and studied in an RCB design with four replications of each treatment: Zero N, 30, 60 and 90 ppm N in the irrigation water. Additional soil application equivalent to one fertigation treatment was also included. The fertilizers were injected into the irrigation water by means of an injection pump. Garlic was planted in plot with dimensions of 3m × 4.5m. Irrigation was applied to replenish 80% of the Class A pan evaporation on a weekly bases. Access tubes for neutron probe reading were mounted in each plot in three replications. The readings were taken before and after each irrigation or rainfall at 15, 30, 45, 60 and 90 cm soil depth. The labelled N fertilizers (^{15}N) were applied to microplots which contained five plants within each plot. At harvest, plant samples were taken from the microplots for the ^{15}N measurements. Plant samples were collected and prepared according to the instructions for sampling for ^{15}N analysis. The yield and its components were obtained from the macroplot. The yield continued to increase with increasing N fertigation rates. The fresh weight per head and per segment showed a similar trend as the yield did. However, the number of segments per head was not affected significantly by the investigated treatments in this study. This may indicate that the zero N treatments produced heads with small segments compared to that produced with N application. The dry weight of shoot, segment and segment membrane responded positively to the rates of N fertigation, reaching the maximum value at the rates of 80 and 120 kg N, irrespective of N fertigation or soil application. The soil application gave a production as high as the best fertigated N rate but lower than the zero N treatment. The percentage of N content in fruits and leaves was the highest with the fertigation treatments where the lowest value was obtained with the zero N rate. The N content was lower with the soil application treatments. A similar trend was obtained for the total N uptake. The soil application treatment gave a Ndff value, which was lower than the fertigated treatments for the whole plant. Fertilizer utilization by fruits was lowest for the soil application treatments compared to the fertigation treatments. No significant differences were obtained among the fertigation treatments themselves. Weekly water consumption ranged from about 10 mm at the beginning of the growing season to about 37 mm at mid season. The crop coefficient Kc was about 0.5 at the earlier growth stages; then it increased to 0.95 at growth stages of the maximum growth. Water use efficiency was the highest for the N2 fertigation treatments. The fertigation treatment (N2) had a higher water use efficiency than the soil application of the similar rate. The maximum water depletion was observed in the top 30 cm.

1. INTRODUCTION

Application of fertilizers with irrigation water (fertigation) has several advantages over the traditional methods. By fertigation, the time and rate of fertilizer applied can be regulated precisely. This will also ensure the application of the proper amount of N to the particular growth stage. This will improve the N use efficiency, decrease leaching and volatilization losses and minimize ground water contamination. In addition, applying N fertilizer in the irrigation water is a more convenient and less expensive method compared to the traditional methods [1]

Trickle irrigation is considered the most efficient method compared to others [2., 3]. Moreover, the additions of chemical fertilizers through irrigation water was found to be the most efficient method of fertilizer application [4, 5, 6]. Papadopoulos [7] found that with fertigation a high yield and very high quality of potato could be obtained. It was also found that the fertilizer use efficiency was affected by the amount of irrigation water [8]. Starck et al. [9] reported that potato responses to split N application with varying amounts of excessive irrigation were not similar. They found that biweekly N application produced higher yields than weekly N applications at all irrigation levels. Kremer [10] found that application of 189 kg/ha gave the highest yield under drip irrigation systems.

Modern irrigation systems are already widely used in Jordan and are continually expanding. These irrigation systems proved to increase the water use efficiency and therefore decrease the losses of water by evaporation and leaching as observed with traditional irrigation systems. Moreover, Jordan is suffering from the scarcity of irrigation water resources. All these factors promoted the growing concern to adapt the new irrigation systems among the farmers in Jordan. On the light of the recent developments and of the alteration in the irrigation systems in the irrigated agriculture, the traditional fertilization practices must be accordingly changed and re-evaluated to match the requirements and conditions created by this development. All elements of the fertilization program must also be re-evaluated and tested to develop updated guidelines for proper fertilization recommendations for the major crops.

Garlic is considered one of the main vegetable crops grown in Jordan. Marketing traditional vegetable crops such as tomato, eggplant and squash is a serious problem for the farmers. The high net return for the farmers by growing garlic stimulated some of them to replace the traditional vegetable crops by growing easily marketable crops such as garlic.

Little research has been conducted to nutrient and water management of garlic. Proper management would aim to increase crop production, increase N and water use efficiencies and decrease cost of fertilizer and minimize environmental pollution from chemical fertilizers.

The goal of this study was to increase water and fertilizer use efficiency. The specific objectives of this study were:

i) comparison of the conventional fertilization method with fertigation;
ii) evaluation of the water and nitrogen use efficiency of both methods of application;
iii) estimation of the crop water requirements and evaluation of the water use efficiency as affected by methods of application and rates of N fertigation; and
iv) evaluation of the plant N distribution and water and nutrient distribution in the soil profile.

2. METHODOLOGY

This research was executed at the Research Center of the Jordan University of Science and Technology (JUST). The area is characterized by a warm winter and a hot and long dry summer.

The following treatments were included and studied in an RCB design with five replication of each treatment to achieve the above objectives:

1) N0 = Zero N application
2) N1 = 30 ppm N in the irrigation water
3) N2 = 60 ppm N in the irrigation water
4) N3 = 90 ppm N in the irrigation water
5) NS1 = Conventional single soil application
6) NS2 = Conventional two split soil application

The first four treatments were applied through the irrigation water so that N was applied in each irrigation, except for the zero treatment. Nitrogen as ammonium sulfate was applied in each irrigation to give the required N concentration for each treatment. Phosphorus at a concentration of 30 ppm in the irrigation water as phosphoric acid was added identically to all treatments. Potassium was not applied to any due to high soil K content. The fertilizers were injected into the irrigation water by means of an injection pump. The injection pump was driven by the pressure in the main line. Two injectors were used for injection of the fertilizers into the irrigation water: one for application of N (rates) and the other one for the application of P.

Garlic (cv. Chinese) was planted on December 21, 1996 and harvested on June 30, 1997. Garlic was planted at 20 cm between plants and 50 cm between rows. Plot dimensions were 3m × 4.5m. Each plot contained 6 rows each 4.5m long. Each row had its own irrigation line positioned near the plants.

Emitters were spaced 20 cm apart in the irrigation line. Irrigation was applied to replenish 80% of the Class A pan evaporation on weekly bases.

Access tubes for neutron probe reading were mounted in the middle of the second row of each plot in one replicate. The readings were taken before and after each irrigation or rainfall at 15, 30, 45, 60 and 90 cm soil depth. Water consumption, volumetric water content and water use efficiency were calculated for each treatment.

The labelled N fertilizers (^{15}N) were applied to a microplots which contained five plants within each plot. The microplots were fertigated through an inverted bottle with drippers simulating the drippers of the original irrigation line. The macroplots were fertigated with the drip-irrigation system.

Soil samples were taken before starting the experiment and after harvesting the crop. Soil samples were taken from the soil depths of 0–15; 15–30; and 30–60 cm. Samples were air dried, crushed to pass a 2 mm sieve and analyzed for physical and chemical properties. Some of the major characteristics of the soil before starting the experiment are shown in (Table I). Soil samples were also taken from each plot at the end of the growing season and were treated similarly as mentioned above (Table II). The soil moisture content during the season was monitored using the neutron probe. Yield and yield components were determined after harvesting the crop. Bulbs (segments) and plant tissues were analyzed for dry weight and NPK.

At harvest, plant samples were taken from the microplots where the labelled fertilizers were applied for the ^{15}N measurements. The three middle whole plants in each of the microplot were collected and samples were sorted into aboveground vegetative biomass (shoot) and fruits. Samples were oven dried at 68 °C and weighted to get the dry matter for each sample. Samples were ground to pass a 1 mm sieve and stored for tissue analysis. Plant samples were collected and prepared according to the instructions for sampling for ^{15}N analysis.

At harvest, the yield was recorded by harvesting the middle three rows and the yield was calculated on a hectare basis. Plant shoots and fruits samples taken from the macroplot receiving the non labelled N fertilizers were oven dried at 68°C and weighted to get the dry matter for each sample. Samples were then ground to pass a 2 mm sieve and analyzed for nutrients.

3. RESULTS AND DISCUSSIONS

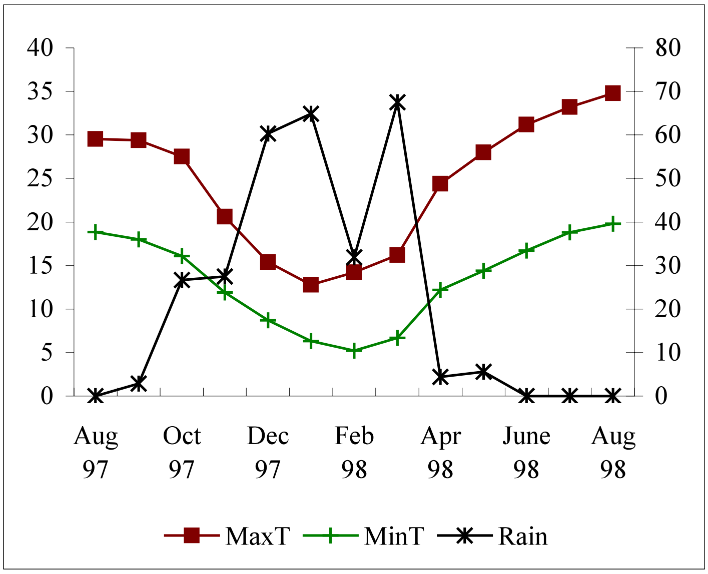
The area of the research site is characterized by an aridic moisture regime. The rainy season extends from October to April where the highest amount of precipitation occurs during January and March (Fig. 1). The soil of the research site is characterized by being alkaline, calcareous and fine textured. This soil also contains a low organic matter content, low amount of soluble salts, a moderate P content but an adequate amount of available K (Table I).

The absolute amounts of N applied through the irrigation water were 0, 60, 120 and 180 kg N ha$^{-1,}$ and 180 and 120 kg N ha^{-1} for the single (base) and split soil application treatments, respectively, for the 1996/1997 growing season; for the 1997/1998 growing season, it was 0, 70, 140, 210 kg N ha^{-1} and 120 kg N ha^{-1} for both the single (base) and split soil application treatments, respectively.

The amount of fertigation water (irrigation water with N fertilizers dissolved in it) applied was 200 mm in the 1996/1997 season and 250 mm in the 1997/1998 season. The absolute amount of P applied as phosphoric acid in the irrigation water was 50 and 70 kg P ha^{-1} for the 1996/1997 and 1997/1998 season, respectively. The soil test values for K indicated the presence of an adequate amount of this nutrient in the soil for normal growth. Therefore, K was not applied. The amount applied in the NS1 treatment (180 kg N ha^{-1}) was higher than in NS2 (120 kg N ha^{-1}) because towards the end of the 1996/1997 growing season we were not able to add the third split application, because of the earlier maturation of the crops. However, in the 1997–1998 season, both the single and the split soil application of the N fertilizers were identical (120 kg N ha^{-1}).

TABLE I. GENERAL CHARACTERISTICS OF THE SOIL AT THE RESEARCH STATION

Soil parameters	Soil depth, cm		
	0 – 15	15 - 30	30 - 60
pH, 1:1	7.71	7.60	7.70
EC, 1:1 (dS $m^{-1)}$	0.44	0.58	0.18
$CaCO_3$ (%)	13.2	14.8	23.2
OM (%)	0.69	0.93	0.10
Total N (%)	0.08	0.08	0.03
$NaHCO_3$-P (mg kg^{-1})	11.6	10.0	10.7
K (mg kg^{-1})	650.0	560.0	270.0
CEC (cmol kg^{-1})	37.5	37.5	-
Sand (%)	7.5	9.0	10.9
Silt (%)	66.1	66.6	69.0
Clay (%)	26.4	24.4	20.0
Texture Class	Silt Loam	Silt Loam	Silt Loam



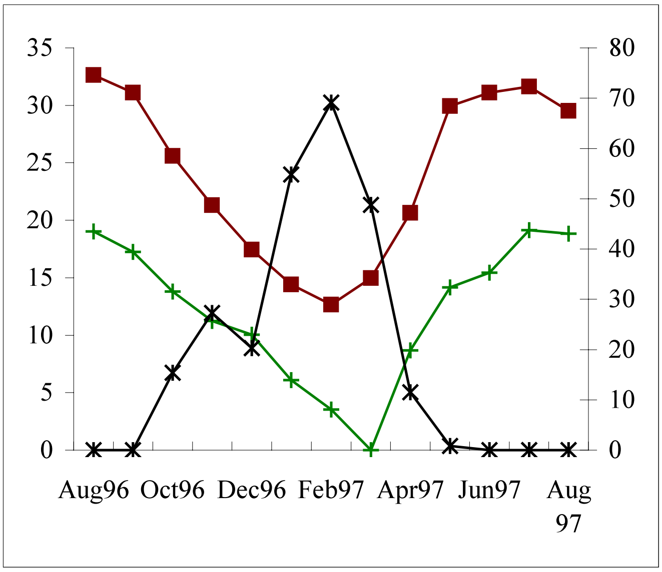


Fig. 1. The average monthly temperature and total precipitation during the growing seasons (1996/97 & 1997/98).

3.1. The 1996/1997 experiment

3.1.1. Yield and yield components

The fresh weight of fruits (yield) continued to increase with increasing N fertigation rates in the range from zero to 120 kg N ha^{-1} (Fig. 2). The soil split application of 120 kg N ha^{-1} gave a higher yield than the zero N treatment and the 60 kg N ha^{-1} but a lower one than the 120 kg N treatment at the 0.1 level of significance. The soil application of 180 kg N ha^{-1} gave a yield as high as that obtained by the soil application of 180 kg N ha^{-1}.

The fresh weight per head and per segment (bulb) showed a similar trend as the yield did (Fig. 3). However, the number of segments per heads was not affected significantly by the investigated treatments in this study (Fig. 4). This may indicate that the zero N treatments produced heads with small segments compared to those produced with N application.

The dry weight of shoot, segment and segment membrane responded positively (Fig. 5) to the rates of N fertigation reaching the maximum value at the rates of 80 and 120 kg N whether N was fertigated or soil applied. The soil application gave also yield values as high as the best fertigated N rate but lower than the zero N treatment.

3.1.2. Nitrogen utilization

Nitrogen utilization by fruits and leaves are presented in Table III. The % of N in the fruits and leaves was the highest with the fertigation treatments where the lowest value was obtained with the zero N rate. The N content was lower with the soil application treatments. A similar trend was obtained for the total N uptake.

The Ndff value was the lowest for the single split soil application treatment. The soil application treatment gave a Ndff value which was lower than the fertigated treatments for the whole plant (fruits and leaves).

Fertilizer utilization by the fruits was lowest for the soil application treatments as compared to the fertigation treatments. No significant differences were obtained among the fertigation treatments themselves.

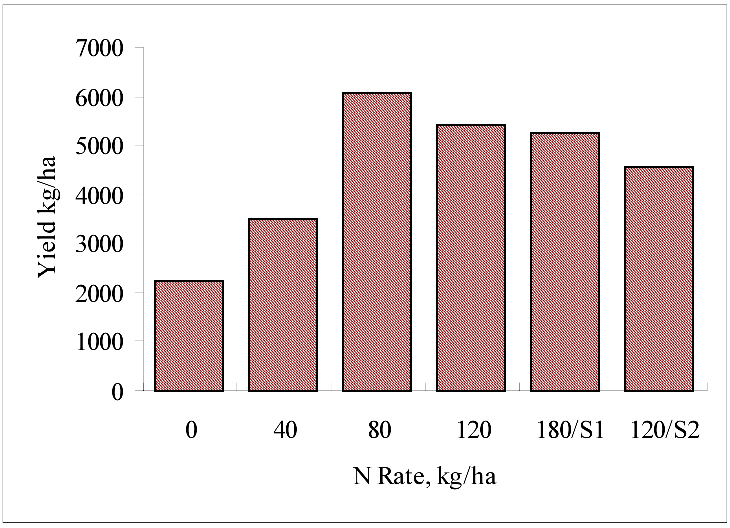
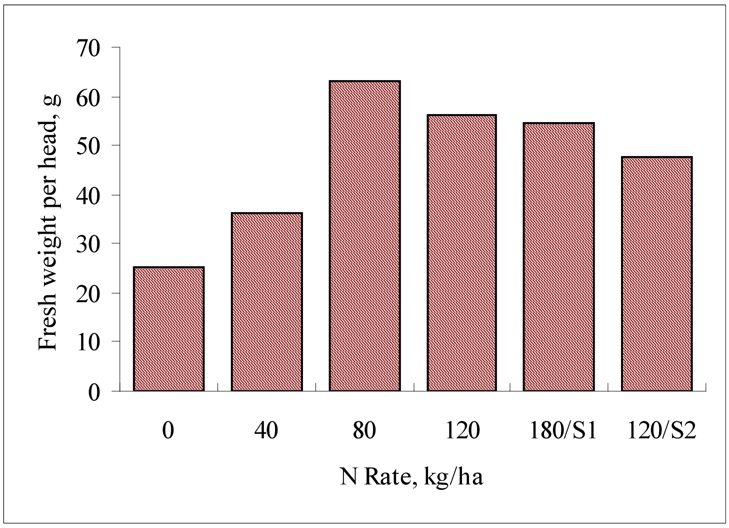


Fig. 2. Fresh weight of marketable heads per ha as affected by N rates.



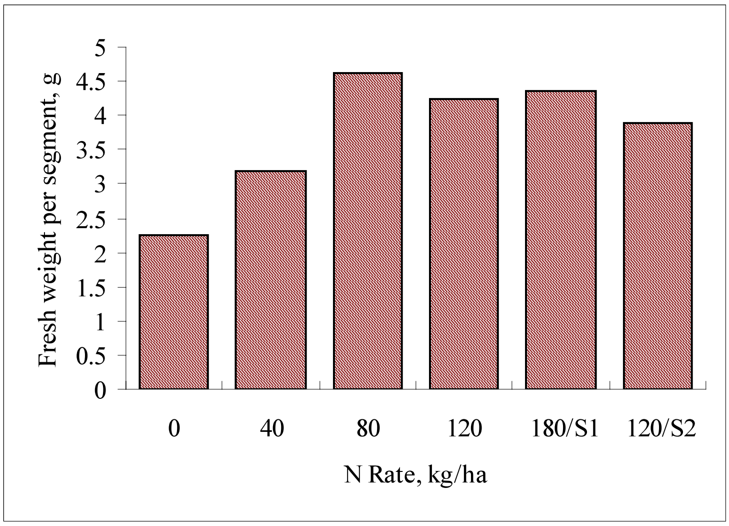


Fig. 3. Fresh weight per head and per segment as affected by N rates.

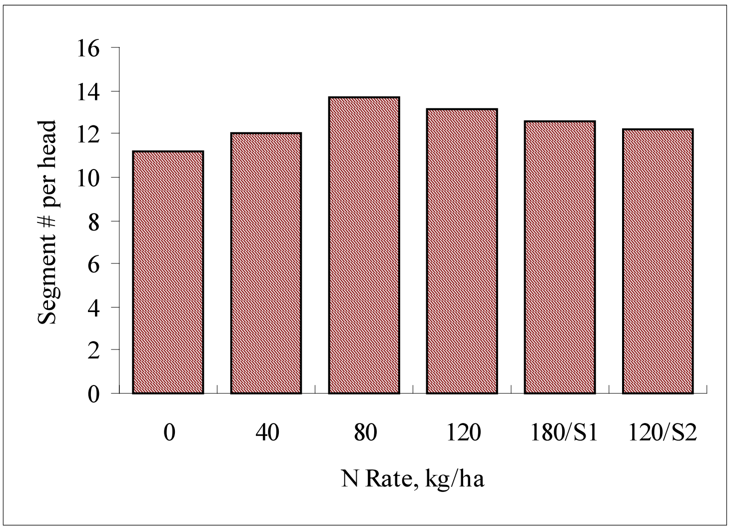


Fig. 4. Number of segments per head as affected by N rates.

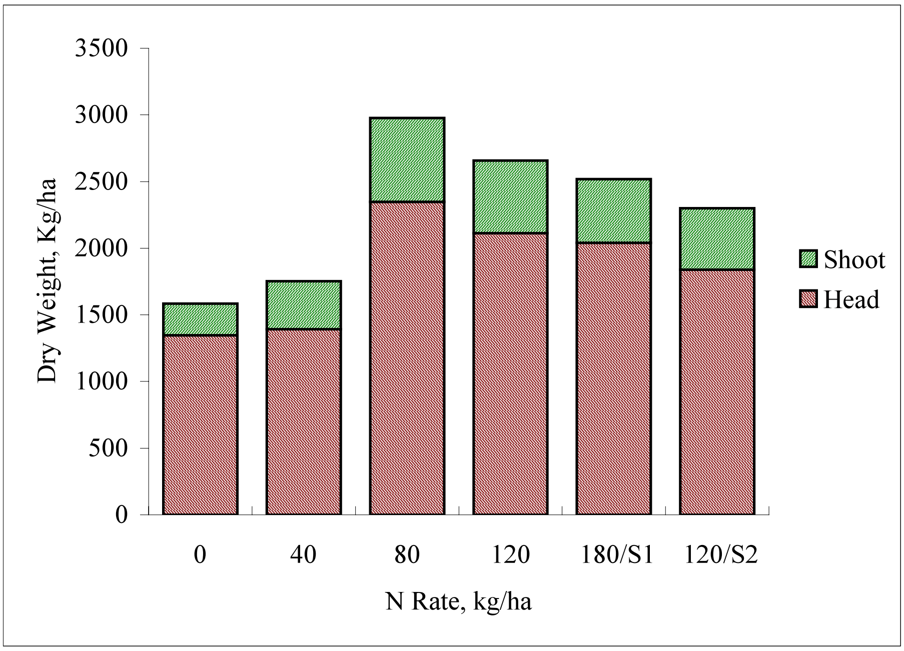


Fig. 5. Dry weight of segments, segment membrane and shoot per ha as affected by N rates.

TABLE II. SOIL CHARACTERISTICS AT THE END OF THE STUDY PERIOD

Trts	Soil Depth, cm	pH	EC dS/m	P ppm
No	0–15	8.25	0.39	37.6
	15–30	8.01	0.24	11.7
	30–60	8.11	0.43	7.5
N1	0–15	7.95	0.63	32.7
	15–30	8.02	0.36	9.9
	30–60	8.03	0.38	5.8
N2	0–15	7.86	0.83	27.6
	15–30	7.92	0.62	9.8
	30–60	7.98	0.49	6.3
N3	0–15	7.67	1.49	21.6
	15–30	7.74	0.78	6.5
	30–60	7.87	0.67	4.9
NS1 (single soil Ap.)	0–15	8.01	0.49	35.7
	15–30	7.86	0.27	10.8
	30–60	8.04	0.3	9.5
NS2 (split soil ap.)	0–15	7.99	0.27	34.1
	15–30	7.86	0.25	9.9
	30–60	8.02	0.35	9.1

TABLE III. NITROGEN FERTILIZER UTILISATION BY GARLIC:

CROPPING SEASON 1996–1997

Treat-Ments *	N (kg/ ha)	Fruit N (%)	Shoot N (%)	Fruit Ndff (%)	Shoot Ndff (%)	Fruit N (kg/ha)	Fruit Ndff (kg/ha)	Shoot N (kg/ha)	Shoot Ndff (kg/ha)	Total Ndff (kg/ha)	Total N recovery (%)
N0	0	2.74	0.58			31.66					
N1	60	3.01	0.89	21.01	15.63	44.47	9.34	7.20	1.18	10.52	17.53
N2	120	3.21	0.99	29.09	22.26	70.48	20.37	14.33	3.26	23.63	19.70
N3	180	3.22	0.99	41.01	31.44	66.75	26.98	18.96	6.24	33.22	18.46
Ns1	180	2.74	0.96	20.61	20.83	55.09	11.34	10.32	2.23	13.58	11.31
Ns2	120	2.79	0.78	11.75	10.66	50.47	6.19	5.39	0.64	6.83	3.79

*N1, N2, N3; 30, 60, 90 ppm in the irrigation water; Ns1 and Ns2, Conventional single and two split soil applications.

CROPPING SEASON 1997–1998

Treat-Ments *	N (kg/ ha)	Fruit N (%)	Shoot N (%)	Fruit Ndff (%)	Shoot Ndff (%)	Fruit N (kg/ha)	Fruit Ndff (kg/ha)	Shoot N (kg/ha)	Shoot Ndff (kg/ha)	Total Ndff (kg/ha)	Total N recovery (%)
N0	0	2.38	0.97								
N1	70	3.23	1.23	27.08	24.93	71.38	19.15	10.69	2.75	21.90	29.20
N2	140	3.45	1.41	32.38	29.68	77.96	25.04	13.88	4.40	29.44	19.63
N3	210	3.52	1.42	34.09	32.64	68.71	24.02	14.35	4.88	28.90	12.85
Ns1	120	3.00	1.50	18.68	19.25	46.02	8.51	5.41	1.06	9.57	7.98
Ns2	120	3.04	1.26	23.39	16.17	57.04	13.09	5.96	1.01	14.10	11.75

* N1, N2, N3; 30, 60, 90 ppm in the irrigation water; Ns1 and Ns2, Conventional single and two split soil applications.

3.1.3. Water utilization

Weekly water consumption ranged from about 10 mm at the beginning of the growing season to about 37 mm at mid season (Fig. 6). The maximum values were observed during the first two weeks of May. Water consumptive use was the highest for the application of 60 and 120 kg N ha^{-1} for the fertigation treatments. This was mainly observed during the period of maximum water use.

The crop coefficient, Kc, was about 0.5 at the earlier growth stages; it increased to 0.95 at the growth stages of maximum growth. Later, towards the end of the growing season, the Kc decreased to 0.5 again (Fig. 7).

Total water consumption was highest in N1 and N2 treatments (Fig. 8). The water use efficiency calculated as yield per unit of water use (kg yield/m^3 water) was the highest for the N2 fertigation treatments. It tended to increase with the increase in N application. The fertigation treatment (N2) had higher a water use efficiency than the soil application of the similar rate.

The percentages of water depleted from different soil depths as affected by the treatments are shown in Fig. 9. The maximum percentage was observed in the top 30 cm. Water uptake from the subsoil (30–60 cm) was higher for the fertigation at 120 kg N ha^{-1} than the soil application of the same amount.

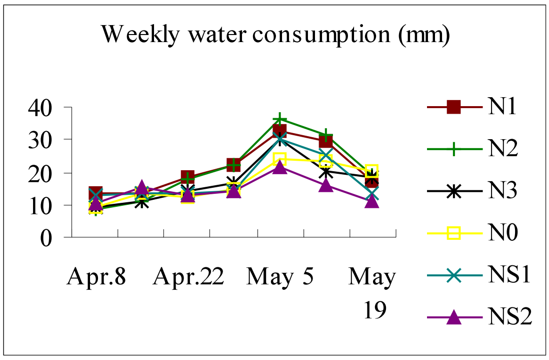


Fig. 6. Weekly water consumption, 1997.

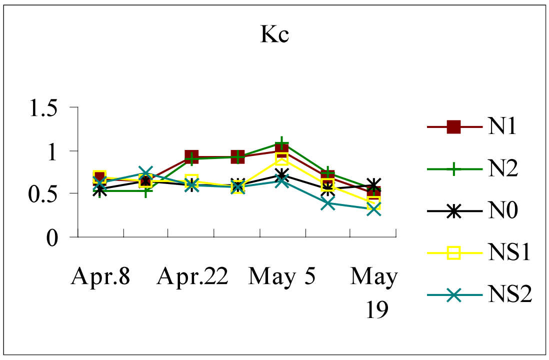


Fig. 7. Crop coefficient (Kc) , 1997.

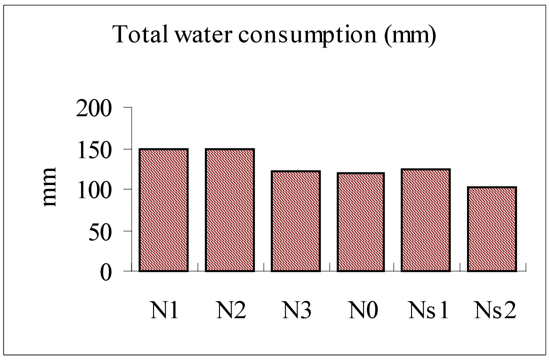


Fig. 8. Total water consumption, 1997.

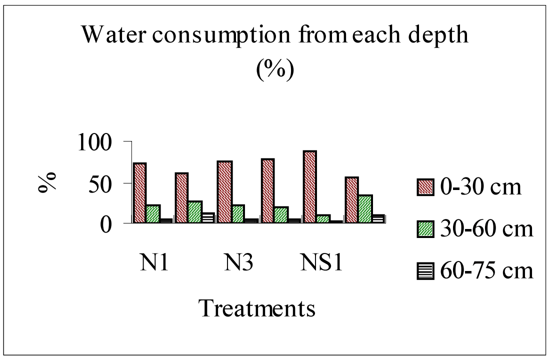


Fig. 9. Percentage of water consumption with soil depths, 1997.

3.2. The *1997/1998 experiment*

3.2.1. Yield and yield Components

All fertigation treatments gave a high yield as compared to the zero N treatment and the soil application The yield tended to decrease with the highest N fertigation rate. Split soil application gave a higher yield than the single soil application. The fresh weight per segment followed a similar trend as the yield did while the number of segments did not change significantly, suggesting that the yield difference is mostly due to the weight of the segments rather than to their numbers. The dry weight of fruit and shoot as well as the weight per head showed a similar trend as the yield.

3.2.2. Nitrogen utilization

The percentage of N content in fruits and leaves was the highest with the fertigation treatments, where the lowest value was obtained with the zero N rate. The N content was lower for the soil application treatments. A similar trend was obtained for the total N uptake.

The N uptake derived from the fertilizers (Ndff) was higher with fertigation as compared to the soil application treatments. The single soil application treatment gave a lower value as compared to the split soil application treatment. This was more obvious for the fruit than for the shoot N uptake. The soil application treatment gave a Ndff value, which was lower than the fertigation treatments for the whole plant (fruits and leaves).

The fertilizer utilization by both fruits and shoot was the lowest for the single soil application treatments followed by the split soil application treatment, but both had a lower fertilizer utilization percentage than the fertigation treatments. With the increasing rates of fertilizers in the fertigation treatments a decrease in fertilizer utilization efficiency was observed. This is different from preceding season where the fertilizer utilization was similar for all fertigation treatments. This might be attributed to the fact that during the second season more N was applied without significant response by the crops.

3.2.3. Water utilization

Water consumption ranged from 469 mm for the zero N treatment to 512 mm for the fertigation treatment of 210 Kg N/ha. However, crops receiving N regardless of rates and application method had more or less similar water consumption (482 – 512 mm). On the other hand, water consumptive use was the lowest for the zero N treatment compared to other treatments. The application of 70 and 140 Kg N/ha as fertigation had a relatively higher consumptive use efficiency compared to the highest fertigation treatment or soil application treatments. Crop coefficient Kc was 0.35 during the initial growth stage, then increased to 1.06 during the mid-season and decreased back to 0.66 during the late season (Fig. 10, 11, and 12).

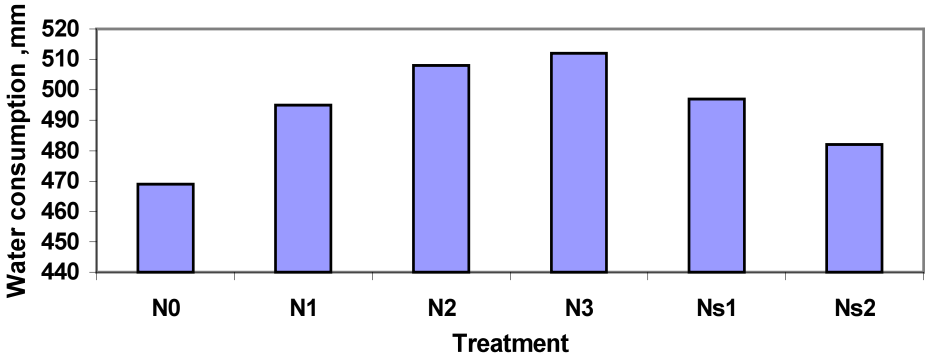


Fig. 10. Seasonal water consumptive use, 1998.

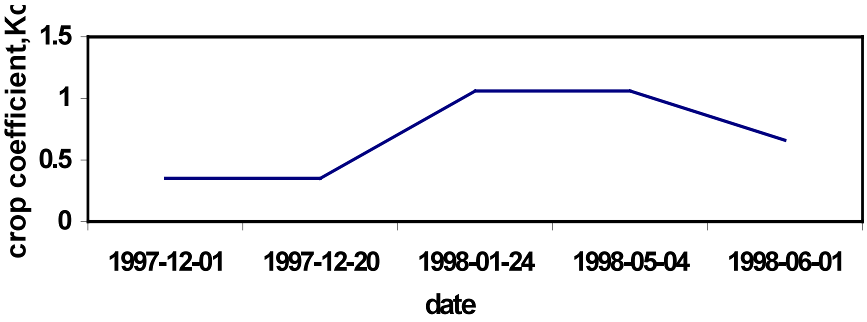


FIG. 11. Garllic crop coefficient, 1998.

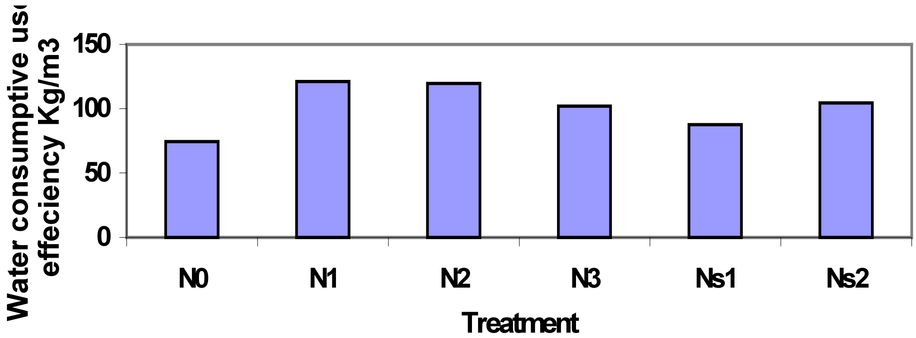


FIG. 12. Garlic water consumptive use efficiency (kg/m^3) 1998.

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MANAGEMENT OF NITROGEN FERTIGATION OF TOMATO WITH THE USE OF ^{15}N TECHNOLOGY

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Abstract

Field studies were conducted during two seasons at the Deir Alla Research Center to compare the conventional fertilization method with fertigation on water and nitrogen use efficiency with a tomato crop (cv. Gardenia). Four N application rates (0, 50, 100 and 150 mg N/L) were applied with the irrigation water and one soil application (NS) treatment, equivalent to one of the fertigation treatments, was included. Labelled ammonium sulfate was applied to microplots within the macroplots to evaluate the N recovery and utilization efficiency. Results obtained from two seasons indicate that increasing the N rate significantly increased the total and marketable yield by both methods of application, suggesting that the crop was underfertilized. The soil application treatment gave a higher yield than the control (N0) and a lower one than the fertigated treatments. In comparison to the N0, the total number of fruits in both seasons was significantly increased at all N levels. The soil application (Ns) treatment gave the lowest number of fruits compared to the fertigation treatments in the first season and a higher number than the fertigated treatments in the second season. The parameters of fruit quality (pH of juice, titratable acidity (TA%) and total soluble solids (TSS%)) were in the acceptable range. They were not significantly affected by the rates and methods of the N application in both seasons. The rates and methods of N application did not affect the accumulation of dry matter (DM) of the fruits and shoots during the first season. But in the second season, the accumulation was higher than in the first season and it was significantly affected by the concentration and method of N application. With the soil application treatment (Ns) a higher DM content was accumulated than in the control (N0), but lower than the fertigated treatments. The total N uptake by the fruits and shoots during both seasons with the fertigated treatments was higher than with the soil application treatment (Ns) and the control (N0). The total N derived from fertilizer (Ndff) in both seasons, obtained by the shoots and fruits decreased as the N concentration increased. Therefore, the lower fertigated treatment gave a significantly higher Ndff content in comparison to the other fertigation treatments and the traditional method (Ns). The soil application treatment gave the lowest Ndff value. The same trend was observed for the shoots and fruits. The result of N utilization indicates that the fertilizer utilization by the fruits and shoots in both seasons tended to be the highest for the lowest N rate fertigation treatment and the lowest for the soil application treatment.

1. INTRODUCTION

Water and nitrogen are the main limiting factors affecting the agricultural production in arid and semi-arid regions. Improving the use efficiency of these critical factors is, therefore, the target of any new management.

Application of fertilizers with irrigation water (fertigation) has several advantages over the traditional methods. By fertigation, the time and rate of fertilizer applied can be regulated precisely. This will also ensure the application of a proper amount of nutrients to the particular growth stage optimizing the nutrient balance in the soil and minimizing the use of soil as storage reservoir for nutrients. This will improve the nutrient use efficiency, decrease leaching and volatilization losses and minimize the chances for ground water pollution. In addition applying the plant nutrients with the irrigation water is a more convenient and less expensive method as compared to the traditional methods [1]. Therefore, fertigation with different plant nutrients should be recommended for farmers in Jordan. It should be used where the plant nutrients use efficiency is low and the cost of fertilizers and wages of labors are high. Moreover, most farmers are switching currently from surface to drip irrigation as a mean to increase water use efficiency. With this in mind the traditional management of plant nutrient application must be modified and adjusted to this new trend.

The main objectives of this study were to compare the conventional fertilization method with fertigation, to evaluate the water and nitrogen use efficiency by both methods of application, and to evaluate the quantity and quality of yield as affected by methods and rates of N application.

2. METHODOLOGY

Two field experiments were conducted at the Deir Alla Regional Research and Technology Transfer Center in 1996/97 and 1997/98. The Center is located in the Jordan Valley, which is characterized by a warm winter and a very hot and long dry summer. Average monthly temperatures range from 30–45°C. The soil is calcareous with a clay loam texture. The major characteristics of the soil at the experimental site are shown in Table I.

TABLE I. MAJOR CHARACTERISTICS OF THE SOIL AT THE DEIR ALLA REGIONAL RESEARCH AND TECHNOLOGY TRANSFER CENTER

Parameters	Units	0–30 cm	30–60 cm
PH		7.7	7.5
EC	Ds /m	1.5	1.1
O.M.	%	1.0	0.52
$CaCO_3$	%	27.0	24.0
Total N	%	0.018	0.009
$NaHCO_3$ — P	ppm	42	20
NH_4OAC — K	ppm	756	625
Ca^{++}	meq/l	12	14
Mg^{++}	meq/l	9.0	11.2
CEC	meq/100g	28.0	29.5
Bulk density	g/cm^3	1.3	1.26
Texture	Clay Loam	Clay Loam	Clay Loam

The following treatments were investigated in a randomized complete block design (RCBD) with four replications:

1–0 ppm N = N0
2–50 ppm N = N1
3–100 ppm N = N2
4–150 ppm N = N3
5- Conventional soil (Ns) application (equivalent to one of fertigation treatments).

The N fertilizer (ammonium sulfate) was applied through the irrigation water with each irrigation in order to provide the required N concentration for each treatment.

The irrigation water was filtered by sand and screen filters. The fertilizer was applied into irrigation water by an injection pump. Tomato plants were planted at 40 cm in rows with two lines and 150 cm between the rows. The plot dimension was 6m × 3.5m. Each plot contained 4 rows, each 6m long. Each row had its own irrigation line positioned between the plants. Emitters were spaced 40 cm apart in the irrigation line (Fig. 1). Irrigation was applied to replenish 80% of the Class A pan evaporation on a weekly basis.

Access tubes for the neutron probe were installed in one place. The reading was mounted in the middle of the second row of each plot. Readings were taken before and after each irrigation or rainfall at 15, 30, 45, 60 and 90 cm soil depth. The labelled ^{15}N fertilizer was applied to the microplots within each plot. The microplots were fertigated through a respirator gallon connected to special drippers that substituted the drippers of the original irrigation line. The macroplots were fertigated with a drip irrigation system.

NS	N2	N3	N0
N1	N0	N2	NS
N0	N3	N1	N3
N2	NS	N0	N1
N3	N1	NS	N2
R-IV	R-III	R-II	R-I

FIG. 1. The experiment design for fertigation of tomato using ^{15}N the Deir Alla Regional Research and Technology Transfer Center; ◂- 6 m - ▸.

Tomato (cv. gardenia) was planted on December 28, 1996, in the first season and on December 5, 1997, in the second season. Red ripe fruits were harvested from the middle two rows for each treatment at weekly intervals. Data of yield and fruit numbers were recorded throughout the harvest season.

Representative harvested fruit samples were collected from each harvest to be analysed for the chemical properties, pH, titratable acidity (TA%), total soluble solids (TSS%), dry matter and the N content. The dry mater content of fruits and shoots was determined by oven drying at 65–70°C. The total N was analysed according to the Kjeldahl method.

For the ^{15}N measurements, representative fruit samples were taken at each harvest, oven dried at 65–70 °C and ground to pass a 2 mm sieve. Two plants from each microplot were collected at the end of the season, dried at 65–70°C and prepared for ^{15}N analysis.

3. RESULTS AND DISCUSSION

3.1. The First Season 1996/97

The amounts of N applied through the irrigation water were 0, 84, 168 and 252 kg N/ha and 168 kg N/ha for the soil application treatment (Table II). The amount of fertigation water applied, including the dissolved fertilizer, was 168.5 mm. 54.2 mm irrigation water without fertilizer was added before the treatments started, in addition to 304.6 mm of rainfall during the growing season (Table II).

There was no significant difference in total and marketable yield between the N fertigation treatments (N1, N2, N3) and the soil application (Ns). However, all these treatments were higher in total and marketable yield with significant differences than the control treatment (N0) (Fig. 2).

The highest yield was obtained with the N3 treatment (70.3 t/ha). The soil application treatment gave a higher yield (67.5 t/ha) than the control treatment (58.4 t/ha) but a lower one than the N2 treatment (69.8 t/ha), which received the equivalent amount of N. It was higher than the N1 treatment (66.4 t/ha), which received the lowest amount of N.

The highest marketable yield was obtained with the N3 treatment (63.8 t/ha). The soil application treatment gave a higher marketable yield (61.1 t/ha) than the control treatment (46.2 t/ha), the N2 treatment (58.9 t/ha) and the N1 treatment (57.6 t/ha). The total number (x 10000) of fruits increased with the increasing N rates: 98.1, 101.8, 127.1, 71.1 , 92.4 for N1, N2, N3, N0 and the soil application (Ns) treatments, respectively (Fig. 3).

Monthly water applied was 43.05, 0.0, 33.48, 47.62, and 98.61 mm, and rainfall was 111.7, 106.0, 75.03, 4.3, 7.3 mm for January, February, March, April and May, respectively (Table III).

TABLE II. TREATMENTS, N APPLICATION, IRRIGATION WATER ADDED AND RAINFALL 1996/1997

Treatments	Amount
N0	0 kg N/ha
N1–50 ppm	84 kg N/ha
N2–100 ppm	168 kg N/ha
N3–150 ppm	252 kg N/ha
NS-soil application	168 kg N/ha
Irrigation water added and rainfall	
Fertilizer water (mm)	168.5
Irrigation water (mm)	54.2
Rainfall (mm)	304.6

TABLE III. IRRIGATION WATER APPLIED AND RAINFALL (mm) DURING THE SEASON 1996/1997

Month	Irrigation water (mm)	Rainfall (mm)
January	43.05	111.7
February	0.0	106.0
March	33.48	75.03
April	47.62	4.3
May	98.61	7.3
Total	**222.76**	**304.6**

The soil application (Ns) treatment gave a lower number of fruits compared to the fertigation treatments, but it was higher than the N0 treatment. The increase in yield was more affected by the increased number of fruits than by the weight per fruit [2].

The chemical properties of the fruits are shown in Fig. 4. The pH of the fruit juice was not significantly affected by the rates and methods of N application, but there was a trend of increasing pH with increasing N concentration. The values were 4.36, 4.37, 4.38, 4.42, and 4.44 for the N1, N2, N3, N0 and soil application (Ns) treatments, respectively.

For the titratable acidity (TA%) all treatments N1, N2, N3 and N0 gave the same value (0.49) while the soil application treatment gave 0.48. This result indicates a decrease in total soluble solids (TSS%) with the increase of N. The N0 treatment gave the highest value, significantly different from the N3 treatment. The values were 4.33, 4.25, 3.95, 4.5 and 4.05 for the N1, N2 , N3, N0, and soil application (Ns) treatments, respectively.

The dry matter of the fruits was increased with the increasing N rates: 2.83, 3.08, 3.32, 2.85 and 1.98 kg/ha for N1, N2, N3, Ns and control (N0) treatments, respectively (Fig. 5). There were no significant differences between the N fertigation treatments and the soil application (Ns) treatments. But all these treatments were significantly higher than the control treatment (N0).

The vegetative (shoots) dry matter was not affected by the N treatments. There was no significant difference between the treatments: 3.57, 3.32, 3.98, 3.35, and 3.47 kg/ha for the N1, N2, N3, N0 and soil application (Ns) treatments, respectively (Fig. 5). This is due to the climatic conditions during the growing season. At the beginning, especially in January after transplanting, the temperature was high and suitable for plant growth. Afterwards, when the plants started to flower the temperature dropped down and reached -0.6°C. The average temperature during February was still less than 15°C (Fig. .6), which means that the fruit failed to set at 13°C or below. It depressed stem elongation, auxiliary shoot and root growth, and leaf initiation.

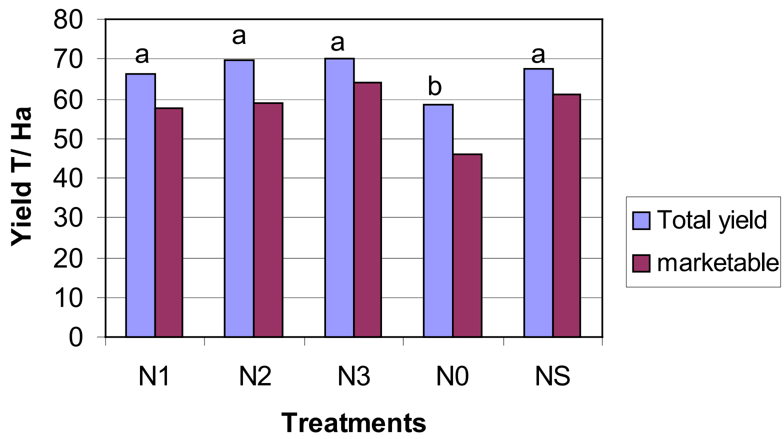

Figure (2): The effect of N rates and methods of application on total and marketable yield of tomato- Jordan Valley-Deir Alla Center 1996/1997.

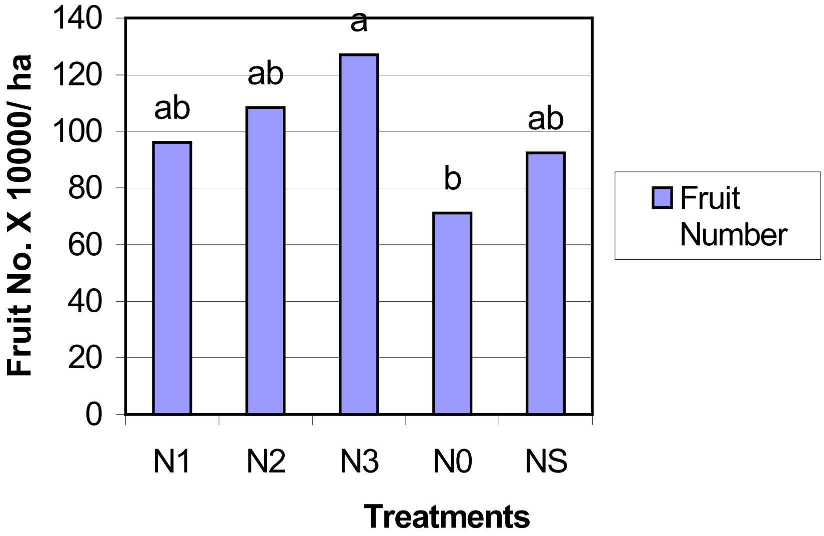

Figure (3): The effect of N rates and methods of application on the fruit number of tomato-Jordan Valley-Deir Alla Center 1996/1997.

Nitrogen Utilization

The N percentage in the total dry matter (fruits and shoots) was not affected by the rates and methods of N applications. However, the fruits contained a higher percentage of N than the shoots (Table IV). The N percentages for dry matter of fruits were significantly different for all N application treatments compared to the control treatment (N0). For the shoots there were no significant differences for all N application treatments compared to the control.

The total N uptake by the fruits and shoots was the highest for the N3 treatment (149 kg N/ha). It differed significantly in comparison to the other fertigation treatments and the soil application (Ns) treatment. All fertigation treatments and the (Ns) were significantly higher than the control treatment (96.7 kg/ha).

The N uptake by the fruits was highest for the N3 treatment (90 kg N/ha). There was no significant difference with the other fertigation and Ns treatments. However, there was a significant difference between all fertigation and Ns treatments compared to the N0 treatment (46 kg N/ha). For the shoots no significant difference was found between the N uptake among all treatments. The quantity of N uptake by the shoots ranged from 47.8 to 59.4 kg N/ha (Table IV). The increase in N uptake was probably caused by a N diffusion gradient, because of the dense root system.

The total nitrogen derived from the fertilizer (Ndff) for the shoots and fruits decreased with the increasing N concentration. The N1 treatment showed (39.2 kg N/ha) a significantly higher content in comparison to the other fertigation treatments and the traditional method (Ns). The soil application treatment showed a lower content than the fertigation treatments (12.8 kg N/ha) (Table IV).

TABLE IV. NITROGEN UTILIZATION BY TOMATO FRUITS AND SHOOTS 1996/1997

Treatments	% N	N Uptake kg/ha	% Ndff	Ndff kg/ha	% fertilizer utilization
			Fruits		
N1 — (N50 ppm)	2.69a	76.2a	26.60	21.75a	25.89a
N2 — (N100 ppm)	2.57a	79.2a	24.90	19.72a	11.73b
N3 — (N150 ppm)	2.71a	90.2a	13.32	12.01b	4.76c
Ns = N2	2.72a	77.6a	13.97	10.84b	6.45c
N0	2.32a	46.0b	-	-	-
			Shoots		
N1 — (N50 ppm)	1.64a	58.8a	26.03	17.46a	20.80a
N2 — (N100 ppm)	1.67a	55.6a	21.72	9.28b	5.50b
N3 — (N150 ppm)	1.49a	59.4a	14.07	4.88c	1.90c
Ns = N2	1.37a	47.8a	8.53	1.99d	1.20c
N0	1.51a	50.7a	-	-	-
			Fruits and shoots		
N1 — (N50 ppm)	2.10a	135.0b	29.0	39.21a	46.6a
N2 — (N100 ppm)	2.09a	134.8b	21.5	29.00a	17.2b
N3 — (N150 ppm)	2.04a	149.6a	11.2	16.89b	6.7c
Ns = N2	2.35a	125.4b	10.2	12.83b	5.1c
N0	1.52b	96.7c		-	-

* Means for fruits, shoots and total followed by the same letter within a column are not significantly different at 5% level according to DMR analysis.

	Treatments
N0 ppm	0 kg N\ha
N1 — 50 ppm	84 kg N\ha
N2 — 100 ppm	168 kg N\ha
N3 — 150 ppm	252 kg N\ha
NS — Soil application	168 kg N\ha

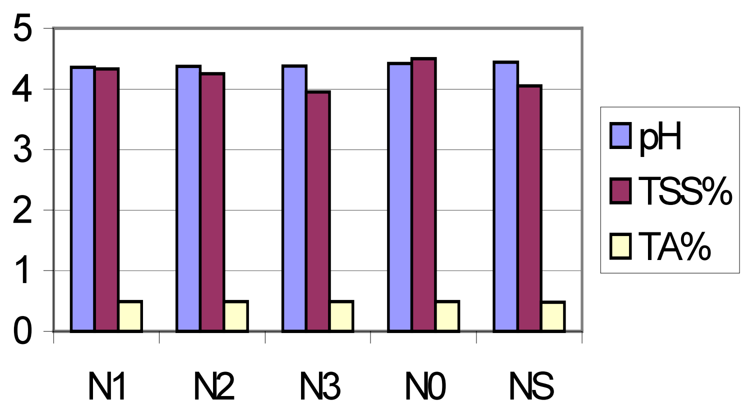

Figure (4): The effect of N rates and methods of application on the chemical properties of tomato fruits — Jordan Valley-Deir Alla Center 1996/1997.

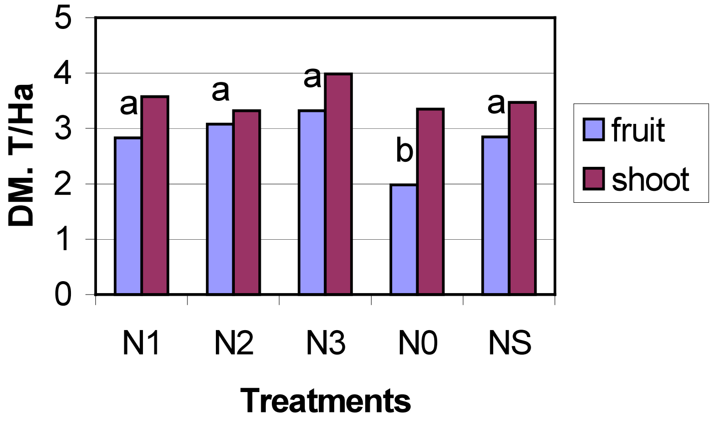

Figure (5): The effect of N rates and methods of application on the dry matter of tomato fruits & shoots — Jordan Valley-Deir Alla Center 1996/1997.

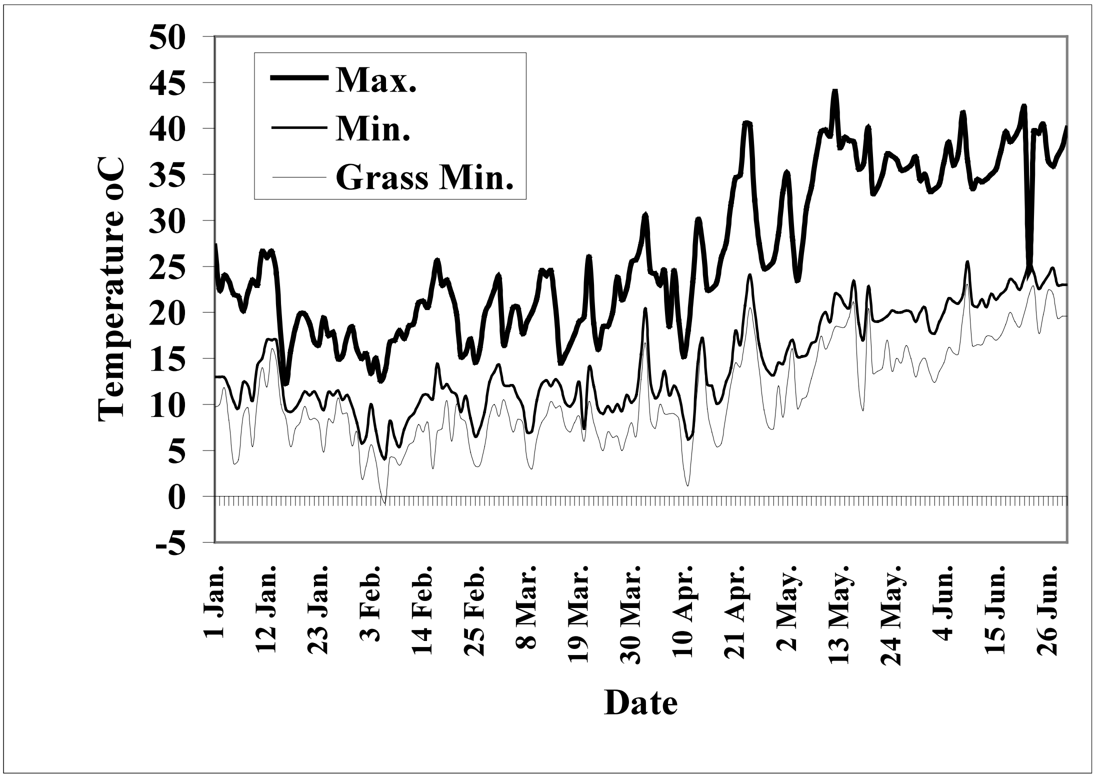

Figure (6): The maximum, minimum, and grass minimum temperature — Jordan Valley. Deir Alla Center 1996/1997.

The Ndff for the fruits was significantly higher for N1 (21.75 kg/ha) and N2 (19.72 kg/ha) than for N3 (12.01 kg/ha) and Ns (10.8 kg/ha). The Ndff for the shoots was the highest for N1 (17.4 kg/ha) and significantly different from the fertigation and Ns treatments. The Ndff for the soil application (Ns) treatment was the lowest (1.99 kg/ha) and significantly different from the fertigation treatments.

The fertilizer N utilization by the fruits and shoots was decreased with increasing N concentration. The fertilizer N utilization by the total tomato crop (fruits and shoots) was the highest for the N1 treatment. It reached 46.6%, significantly different from the other fertigation and soil application treatments. The fertigation treatments had a higher fertilizer N utilization (17.2% and 6.7% for N2 and N3, respectively) as compared to the soil application treatment, which was 5.1%

(Table IV). The same trend was observed for the fruits and shoots. This could be the result from the N fertilizer being leached from the root zone during irrigation as well as from volatilization losses [2].

3.2. The second season 1997/98

The amounts of N applied through the irrigation water were 0, 64, 128 and 192 kg N/ha and 175 kg N/ha for the soil application treatment (Table V). The amount of fertigation water (including the dissolved fertilizer) applied was 128.7 mm. And 56 mm irrigation water without fertilizer was added before the treatments started, in addition to 333.1 mm of rainfall during the growing season (Table V).

TABLE V. TREATMENTS, N APPLICATION, IRRIGATION WATER ADDED AND RAINFALL, 1997/1998

Treatments	Amount
N0 — ppm	0 kg N/ha
N1 — 50 ppm	64 kg N/ha
N2 — 100 ppm	128 kg N/ha
N3 — 150 ppm	192 kg N/ha
NS — Soil application	175 kg N/ha
Irrigation water added and rainfall.	
Fertilizer water (mm)	128.7
Irrigation water (mm)	101
Rain (mm)	337.3

It should be noted that the amount of N added by the soil application treatment in the first season was equivalent to amount of N in the fertigated treatment N2 (168 kg N/ha), while in the second season the amount was 175 kg N/ha, which was closer to the highest amount of N in the fertigated treatment N3 (192 kg/ha).This was due to the differences in the quantity of fertigation water in both seasons.

The amounts of monthly water applied were 11, 0.0, 32, 61, 89 and 36.7 mm, and rainfall was 72, 122, 89, 35, 15.7 and 3.6 mm for December, January, February, March, April and May, respectively (Table VI).

The results indicate that the total and marketable yield responded positively to the fertigation. The total and marketable yield from the fertigation treatments significantly differed from the soil application treatment (Ns). All these treatments produced a higher total and marketable yield, significantly different from the control treatment (N0) (Fig. 7).

TABLE VI. IRRIGATION WATER APPLIED AND RAINFALL (mm) DURING THE SEASON, 1997/1998

Month	Irrigation water (mm)	Rainfall (mm)
December	11	72
January	0.0	122
February	32	89
March	61	35
April	89	15.7
May	36.7	3.6
Total	229.7	337.3

The highest yield was obtained with the N3 treatment (80.4 t/ha). The soil application treatment gave a higher yield (68.2 t/ha) than the control treatment (58.4 t/ha) but a lower one than the N2 (79.7 t/ha) and N1 treatments (75.16 t/ha) which received the lowest amount of N. There were significant differences in yield between the fertigation treatments and the soil application treatment (Ns) and N0. Significant differences in yield were also noted between Ns and N0.

The highest marketable yield was obtained with the N3 treatment (64.4 t/ha). The soil application treatment gave a higher marketable yield (50.21 t/ha) than the control treatment (44.9 t/ha), but a lower one than the N2 (61.1 t/ha) and N1 (56.7 t/ha) treatments.

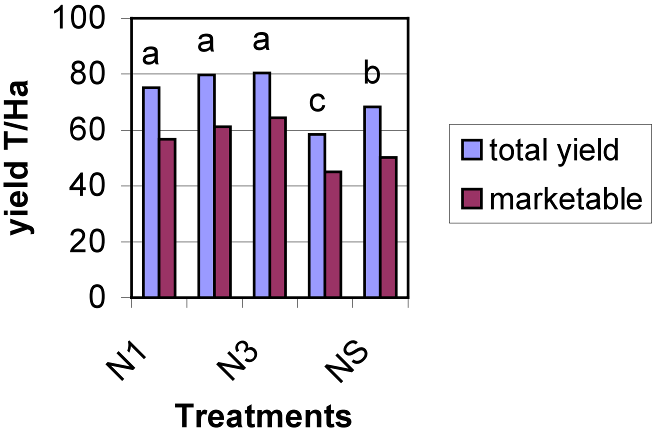

Figure (7): The effect of N rates and methods of application on total an marketable yield of tomato — Jordan Valley-Deir Alla Center 1997/1998.

The number of fruits was increased by increasing nitrogen rates: 88.1, 91.5, 92.2, 95.5 and 70.5 (to be multiplied by 10000) for the N1, N2, N3, Ns and N0 treatments, respectively (Fig. 8). The only significant difference was found between all treatments and the control (N0).

The soil application (Ns) treatment gave the highest fruits number, higher than the fertigation treatments and the N0 treatment.

The chemical properties of the fruits are shown in Fig. 9. The pH of fruit juice was not significantly affected by the rates and methods of N application, but there was a trend of increasing pH with increasing N concentration. The values were 4.53, 4.71, 4.80, 4.33, and 4.91 for the N1, N2, N3, N0 and soil application (Ns) treatments, respectively.

All treatments N1, N2 ,N3 and Ns gave a value ranging from 0.30 to 0.37 for the titratable acidity (TA%) while the N0 gave 0.52. There were no significant differences between all treatments.

The results indicated an increase in total soluble solids (TSS%) with increasing N concentration. The N3 treatment gave the highest value of TSS% with no significant differences between all treatments. The values of TSS% were 3.76, 3.89, 4.20, 3.78 and 3.86% for the N1, N2, N3, N0, and soil application (Ns) treatments, respectively.

The dry matter content of the fruits and shoots was affected by the concentration and method of N application. There were significant differences between the fertigation treatments and the Ns treatment as well as significant differences between Ns and N0 (Fig. 10).

The dry matter accumulated in the fruits was 4.69, 4.79,4.83,4.10 and 3.50 t/ha for the N1, N2, N3, Ns and control (N0) treatments, respectively (Fig. 5).

The shoots accumulated more dry matter than the fruits .The N3 treatment gave the highest quantity of dry matter (5.85 t/ha) with no significant differences as compared to the other fertigation treatments, but with significant differences as compared to the Ns and N0 treatments. The N2 treatment gave the second highest quantity of dry matter (5.65 t/ha), while the N1 treatment was higher than the Ns and N0 (5.50 ton/ha) with significant differences among them. The Ns treatment gave a higher quantity than the N0 treatment (4.75 t/ha) with significant differences as compared to N0 (3.98 t/ha). To understand these results, it is useful to look at the climatic conditions during the growing season 97/98, shown in Fig. 11. The conditions for plant growth were normal. This is indicated by the fact that the accumulated dry matter during the second season was higher than during the first season.

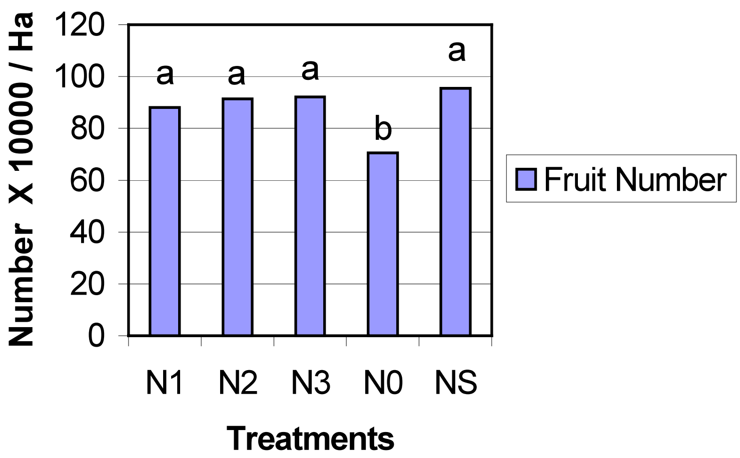

Figure (8): The effect of N rates and methods of application on the fruit number of tomato-Jordan Valley-Deir Alla Center 1997/1998.

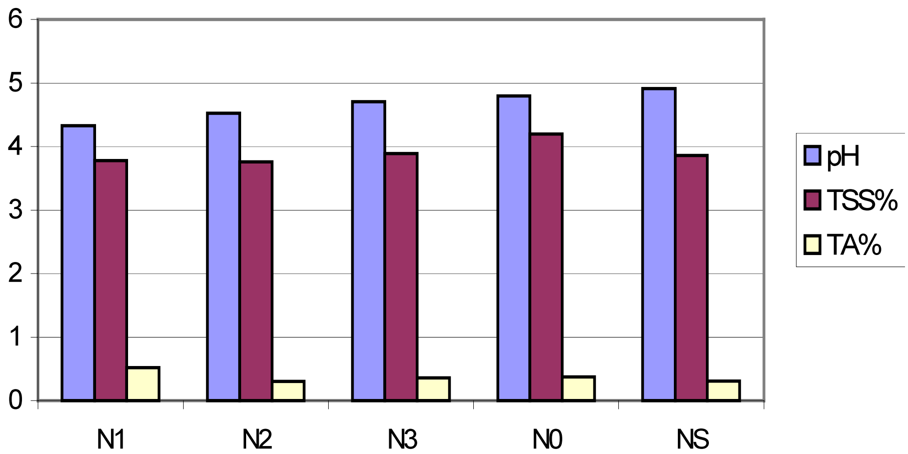

Figure (9): The effect of N rates and methods of application on the chemical properties of tomato fruits — Jordan Valley-Deir Alla Center 1997/1998.

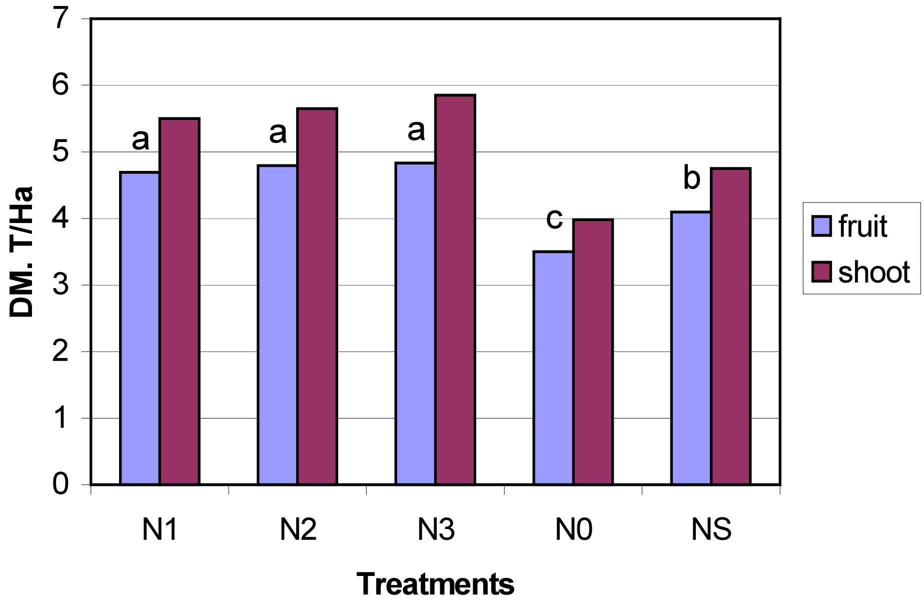

Figure (10): The effect of N rates and methods of application on the dry matter of tomato fruits & shoots — Jordan Valley-Deir Alla Center 1997/1998.

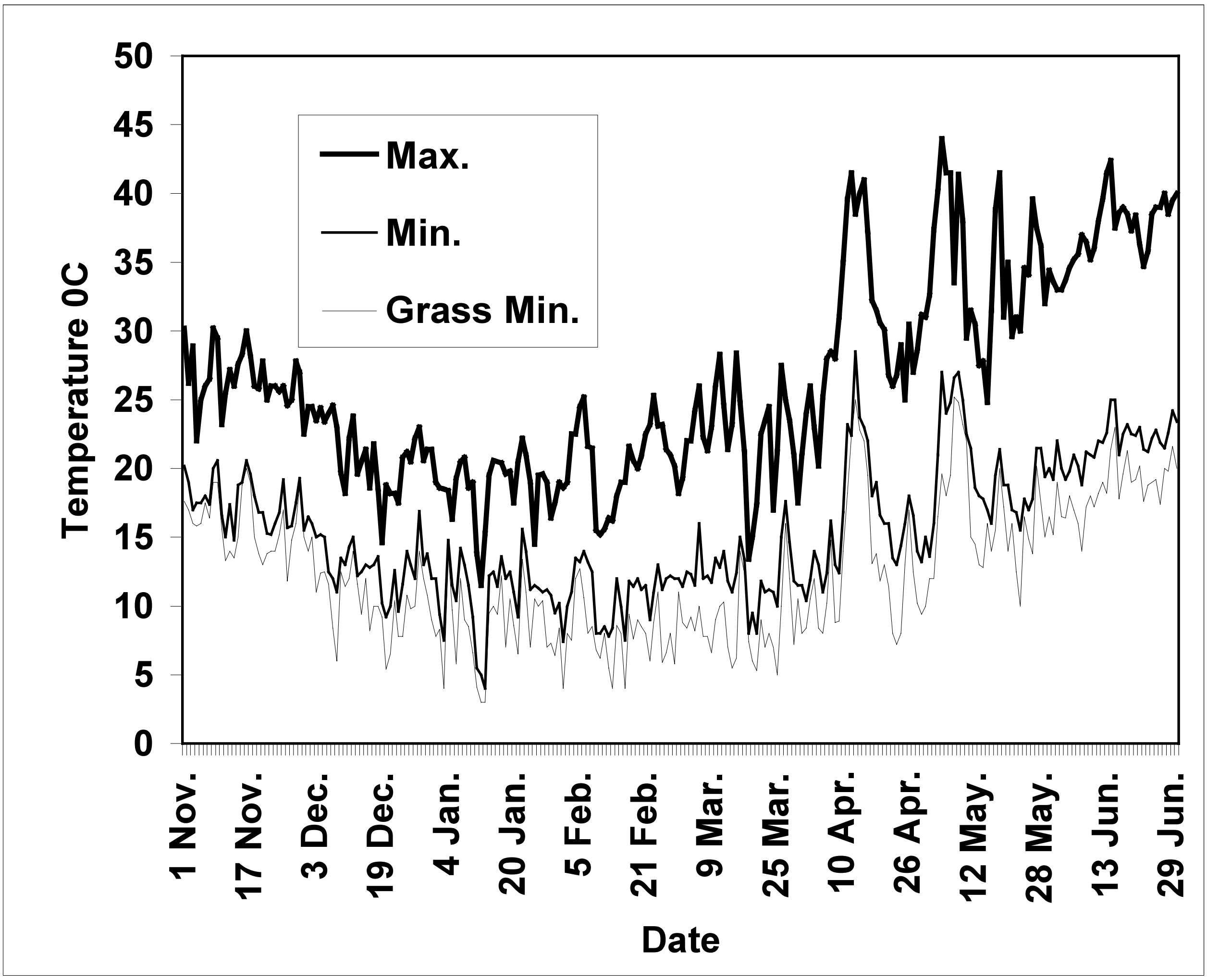

Figure (11): The maximum, minimum, grass minimum temperature — Jordan Valley. Deir Alla Center 1997/1998.

Nitrogen Utilization

Rates and methods of N application affected the N content in the dry matter (shoots and fruits) with a significant difference between all N application treatments and the N0 and Ns treatments. The fruits contained a higher N percentage than the shoots, with no significant difference between all treatments (Table V).

The total N uptake by the fruits and shoots was higher with the fertigation treatments and ranged from 200 to 221 kg N/ha. It differed significantly from the soil (166 kg N/ha) and control (140.3 kg N/ha) treatments.

The N uptake by the fruits was highest at the N3 treatment (90 kg N/ha) with no significant difference with the other fertigation treatments and Ns. But there was a significant difference between all fertigation and Ns treatments and the N0 treatment (88.2 kg N/ha). The N uptake by the shoots was the highest for the fertigation treatments and ranged from 74.5–82.1 kg/ha with a significant difference from the Ns and N0 treatments, ranging from 52–56 kg/ha.

The total N derived from the fertilizer (Ndff) obtained by the tomato crop (shoots and fruits) decreased as the N concentration increased. The N1 treatment gave (30.9 kg N/ha) a significantly higher value than the other fertigation treatments and the traditional method (Ns). The soil application treatment gave a lower Ndff value than the fertigation treatments (10.35 kg N /ha) (Table 4).

The Ndff values for the fruits were significantly higher at N1 (16.87 kg/ha)) than at N2 (12.92 kg /ha), N3 (13.27 kg /ha) and Ns (5.4 kg/ha). All fertigation treatments were significantly different from Ns

The same trend was seen in the Ndff by the fruits and shoots. The Ndff values for fruits were 16.87, 12.92, 13.27 and 5.4 kg/ha at N1, N2, N3 and Ns, respectively. The Ndff values for the shoots were 13.9, 8.78, 8.08 and 4.95 kg/ha at N1, N2, N3 and Ns, respectively .

The % fertilizer N utilization by the fruits and shoots was decreased with the increasing N concentration. It was the highest for the N1 treatment, and reached 48.3% with significant differences as compared to the other fertigation and soil application treatments. The % of N utilization for N2 (16.9%) was significantly higher than for N3 and Ns. The N3 had 11.1% as N utilization with a significant difference as compared to the soil application treatment (Ns), which was 5.1%. (Table V). The same trend was observed for the fruits and shoots. This could be due to the N fertilizer being leached from the root zone during irrigation as well as due to volatilization losses [2].

4. SUMMARY AND CONCLUSION

Increasing the N rate significantly increased the total and marketable yield by both methods of application during both seasons. This suggests that the crop was underfertilized. The soil application treatment gave a higher yield than the control (N0) and a lower one than the fertigated treatments

The total number of fruits in both seasons was significantly increased with all N treatments above the N0 treatment. The soil application (Ns) treatment gave a lower fruit number as compared to the fertigation treatments in the first season and a higher one than the fertigated treatments in the second seasons.

The parameters of fruit quality, pH of the juice, the titratable acidity (TA%) and total soluble solids (TSS%) were not affected by the rates and methods of N in both seasons.

The accumulation of dry matter of the fruits and shoots during the first season was not affected by the rates and methods of N application. But, in the second season the accumulation was higher than in the first season and it was significantly affected by the concentration and method of N application. The dry matter accumulated with the soil application treatment (Ns) was higher than the control (N0) and lower than the fertigated treatments.

TABLE VII. NITROGEN UTILIZATION BY TOMATO FRUITS AND SHOOTS, 1997/1998

Treatments	% N	N Uptake kg/ha	% Ndff	Ndff kg/ha	% Fertilizer Utilization
			Fruits		
N1 — (N50 ppm)	2.76a	129.84a	13.0	16.87a	26.37a
N2 — (N100 ppm)	2.58a	125.51a	10.3	12.92b	10.1b
N3 — (N150 ppm)	2.88a	139.09a	9.55	13.27b	6.91c
Ns (175 kg N/ha)	2.67a	110.07ab	4.91	5.40c	3.09d
N0	2.52a	88.20b	-	-	-
			Shoots		
N1 — (N50 ppm)	1.35a	74.5a	18.66	13.90a	21.71a
N2 — (N100 ppm)	1.33a	75.1a	11.70	8.78b	6.35b
N3 — (N150 ppm)	1.40a	82.1a	9.84	8.07b	4.20c
Ns (175 kg N/ha)	1.18a	56.0b	8.84	4.95c	2.82d
N0	1.31a	52.1b	-	-	-
			Total: fruits and shoots		
N1 — (N50 ppm)	2.17a	204.3a	15.1	30.90a	48.3a
N2 — (N100 ppm)	1.93a	200.6a	10.8	21.70b	16.9b
N3 — (N150 ppm)	1.95a	221.1a	12.8	21.34b	11.1c
Ns (175 kg N/ha)	1.55b	166.0b	6.2	10.35c	5.9d
N0	1.66b	140.3b	-	-	-

* Means for fruits, shoots and total followed by the same letter within a column are not significantly different at 5% level according to DMR analysis.

Treatments	
N0 — ppm	0 kg N/ha
N1 — 50 ppm	64 kg N/ha
N2 — 100 ppm	128 kg N/ha
N3 — 150 ppm	192 kg N/ha
NS — soil application	175 kg N/ha

Ndff (%)= (% plant 15N/% fertilizer 15N) × 100

Ndff (kg/h) =[Ndff (%) × total N uptake]/100

% Fertilizer N utilization = [Ndff (kg/h)/rate of N applied] × 100

Total Ndff (%) = [total Ndff (kg/ha)/total N uptake (kg /ha)] × 100.

The % N in the fruits and shoots during the first season was not affected by the rates and methods of N application. The % N in the shoots plus fruits was significantly affected by the N application rates. During the second season the % N in the fruits plus shoots was significantly affected only by the fertigation treatments. In both seasons, the fruits contained a higher N % than the shoots, with no significant difference between the treatments. The total N uptake by the fruits and shoots of the fertigated treatments during both seasons was higher than the total N uptake of the soil application treatment (Ns) and the control (N0).

The total nitrogen derived from the fertilizer (Ndff) in both seasons, calculated for the shoots and fruits decreased as the N concentration increased. Therefore, the lower fertigated treatment gave a significantly higher content in comparison to the other fertigation treatments and the traditional method (Ns). The soil application treatment gave the lowest value of Ndff. The same trend was observed for the shoots and fruits.

The results of the N utilization indicated that the fertilizer utilization by the fruits and shoots during both seasons tended to be highest for the fertigated treatment rate (N1) and the lowest for the soil application treatment.

The results show that under the experimental conditions, the crop responded positively to the low N rates applied by fertigation to obtain an acceptable yield with a high efficiency of fertilizer use. Moreover, the higher N fertigated rates guide to a non significant increase in yield, with a high reduction in the fertilizer use efficiency. It could have a negative impact on the environment resulting in soil and water pollution. Generally, to reach an acceptable yield with high fertilizers use efficiency we suggest to apply relatively low rates of N fertigation, keeping in mind regional site conditions such as soil, irrigation water, climate, etc.

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MODALITY OF FERTIGATION OF PROTECTED CUCUMBER AND NITROGEN USE EFFICIENCY UNDER FIELD CONDITIONS

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Abstract

Cucumber and tomato are the most important protected vegetables in coastal Lebanon. Recent research established that in these intensive systems, irrigation and fertilization are still empirically applied. Techniques such as fertigation are used but associated to traditional practices of soil application of fertilizers and animal manure addition. In 1997, a pot experiment was conducted in order to find the optimal irrigation frequency and modality of fertigation. For this, four frequencies of irrigation were combined with two modalities: discontinuous irrigation as practiced by the growers and continuous irrigation, as recommended by the scientists. In these closed-system conditions, the frequency of irrigation influenced the dry matter production. In addition, the percentages of nitrogen derived from fertilizers were very high, from 89 to 95%. The discontinuous modality allowed for greater nitrate leaching. The evaluation of the main findings for plants grown in the soil, was conducted in 1998, in a greenhouse, 35 km north of Beirut. The treatments were reduced to two frequencies of irrigation combined with the two modalities of fertigation. The objectives were to assess, with the use of ^{15}N labelled fertilizers, the most efficient treatment as far as plant performance and losses from the plant-soil system are concerned.

1. INTRODUCTION

In Lebanon, protected cultures are, once more, in expansion with indications of new greenhouses installed every year, particularly at altitudes between 400 and 500 m. In these intensive systems, few studies looked at the crop requirements, the management practices and their consequences on the soil and water. A survey conducted on these aspects showed that an overfertilization balanced by an overirrigation was frequent. Input of water and fertilizers was mostly empirically based [1], in the absence of local results and recommendations. Not only the soil status was not taken into consideration, but the nutrients were added according to a discontinuous modality: with every other irrigation.

Based on these findings, it was important to establish the water and nutrients requirements of the predominant crops. This was undertaken for cucumber, as it occupies with tomato, the largest area. For this, the effect of different irrigation frequencies combined with two modalities of fertigation, continuous and discontinuous, on the water and nitrogen balances was studied. In 1997, an experiment including four irrigation frequencies: every one, two, three and four days combined with the two modalities, was conducted in pots [2]. This research indicated that the frequency of irrigation strongly influenced the dry matter production, particularly in the case of plants disposing of relatively small volumes. On the other hand, the modality of fertigation had an impact on the amounts of N lost below the root zone. Discontinuous fertigation increased the leaching of nitrate.

In this paper, a confirmation of some of these results was looked for, under field conditions for a typical spring growing season. Treatments consisted of irrigating every two or three days, continuously or discontinuously, the amount of water and nutrients being otherwise equal. One of the objectives was to study the water balance, which will be discussed in another paper. In this paper, the effect of the frequencies and modalities of fertigation on the plant performance, nitrogen use efficiency and some aspects of N losses in the soil will be presented.

2. EXPERIMENTAL SET-UP

The experiment was conducted under field conditions in Jbeil (35 km north of Beirut) at 100 m of altitude. The unheated greenhouse used for this purpose was oriented north-south and was 8 m large and 39 m long. The soil depth varied between 40 cm (at the east) and 60 cm (at the west near the terrace edge). Because of its stoniness, the soil presented a high permeability. In addition, it had a clay texture, a pH of 7.78, 8.8% of total calcium carbonate, and 2.9% of organic matter.

The treatments consisted of two irrigation frequencies: every two and three days, combined with two modalities of fertigation: continuous and discontinuous, with every other irrigation. This gave all together 4 treatments replicated five times in 5 blocks. The dose of irrigation was based on the evaporation from a mini-pan placed at the west side of the greenhouse [3]. Nutrient levels were based on recommendations for cucumber [4], adjusted in acccordance to previous works in the region [5,6]. This meant in the case of the continuous treatments: 135 mg/L of N (as ammonium sulfate) and 40 mg/L of P (as phosphoric acid) and 200 mg/L of K (as potassium sulfate). The microplots (2 effective plants per plot) received ammonium sulfate enriched with ^{15}N (1.5% a.e.).

To follow eventual nitrate movement in the soil, two sets of tensionics were placed: one set at 25 cm of depth and the other one at 50 cm. Each set was represented in three blocks for the four treatments. Tensionics were emptied every 8 to 10 days and the nitrate concentration analysed on a RQflex2. In addition, soil samples were collected from the wet bulb (15 cm away from the drip) at the beginning and at the end of the experiment and analysed for their salinity and nitrate content.

3. RESULTS

3.1. Plant performance

Over the duration of the experiment (71 days), corresponding to an average spring season in coastal Lebanon, the overall N input for the macroplots was 25.75 g N/m^2 for a population density of 3 plants/m^2.

With regard to the yield, covering a period of 57 days, a significantly higher fruit production per unit area was found for the T2C treatment (Fig. 1). This result indicates the advantage of this modality of input under the experimental conditions, as this could be associated with the fluctuations in salinity. In fact, the irrigation water had an EC of 1.13 dS/m, which is considered as presenting an increasing risk of salinity according to the FAO [7]. Thus, the discontinuous treatments (T2D and T3D) received solutions with a salinity ranging from 1.13 dS/m to 4.56 dS/m, whereas the continuous treatments had a stable salinity of 2. 79 dS/m.

This optimum was not only important for the fresh fruits production but it was also obvious in the number of fruits produced per unit area and particularly in the number of non-commercial fruits (Fig. 2). Therefore, not only more fruits were produced in T2C but also healthier fruits, not submitted to stress as in the other treatments.

Similar results were obtained for the above-ground dry matter production as for the fruits. In order to verify the impact of the salinity on the plant, the plant height was followed across the season. The T2C plants were significantly higher starting from day 78 after sowing, which was 23 days after the beginning of the differential fertigation. This lasted until the day 95. On the other hand, an influence of salinity was found in the microplots of T2C and T2D when the roots were digged, washed and dried. The treatment T2D presented a higher root mass than T2C, all located near the soil surface as there was no difference in rooting depth. Such a strategy is an indication of a stressful environment, and the large root mass is an avoidance of the soil conditions in depth.

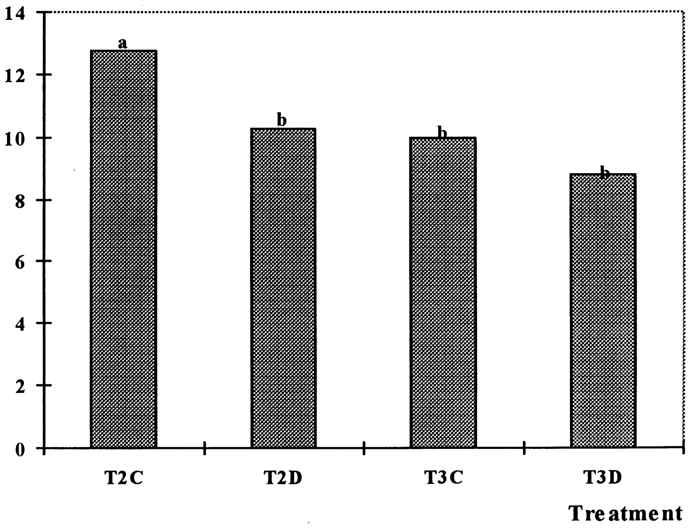

FIG. 1. Fresh fruits production (kg/m2 of cucumber plants from the macroplots, irrigated every 2 T2) or 3 (T3) days continuously © or discontinuously (D).

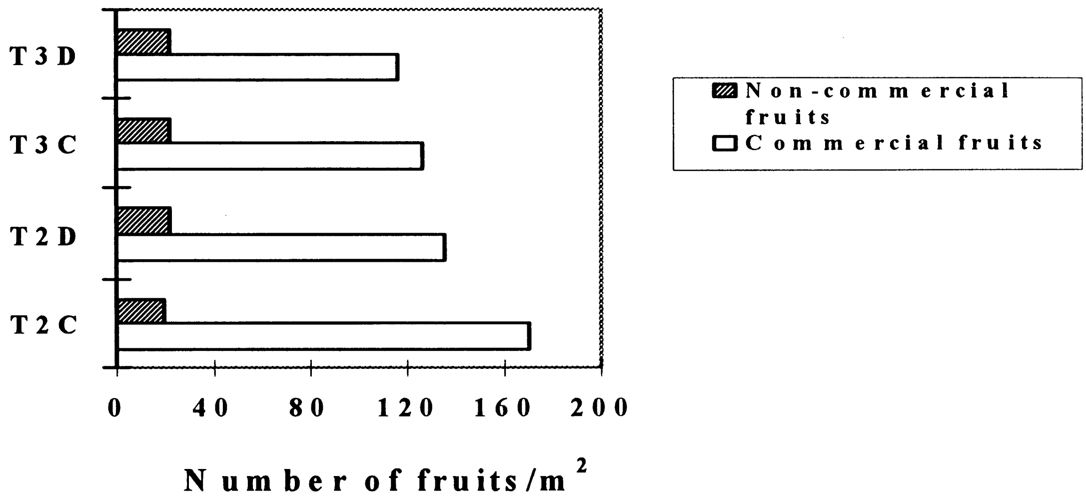

FIG. 2. Number of commercial and non-commercial fruits produced per unit area by cucumber plants irrigated every 2 (T2) or 3 (T3) days continuously © or discontinuously (D).

3.2. Nitrogen in the plants

When considering the macroplots, the nitrogen use efficiency by the fresh fruits per unit of applied N fertilizers was highest for the T2C treatment, with 495 g/g of N. Whereas, it was 398 g for T2D, 388 g for T3C and 341 g of fresh fruit for T3D. Furthermore, the ratio fruits dry matter/shoots dry matter was the highest in the T2C (2.86) and the lowest in the T3C treatment (2).

In the microplots, the use of labelled N fertilizers allowed to study the proportion of nitrogen derived from fertilizers (% Ndff). In fruits and shoots together, the Ndff (%) varied between 54.76% and 69.86%. This proportion was lower in the shoots and fruits of T3C than of the 3 other treatments (Fig. 3). This result could eventually have a link with the lower water consumption in this treatment and a potential capillary rise during the growing season. These values are smaller than in 1997, being between 89% and 94.6% [2], In that case, a closed system (pot experiment) was adopted.

Concerning the fertilizer N utilization (%) by the fruits, the T2 treatments gave higher results than the T3 treatments. This could be due to the significantly higher fertilizer N yield. No statistically significant difference was found in the shoots (Fig. 4). This means that the frequency of irrigation (2 days) was better in ensuring fertilizer N utilization. But, the difference between T2C and T2D remains to be explained. They both used similarly the N from the fertilizers, but T2C performed better in transforming this to fruit production. Fertilizer N utilization, in fruits and shoots added together, was the highest in T2C with 69% and the lowest in T3C with 46.15%. These values are much higher than in 1997, which were lower than 45%, due to the shorter growing season then [2]. The inclusion of roots in the T2 treatments slightly increased the values (70.59% for T2C), indicating the small contribution of roots to the overall N uptake and utilization.

3.2. Nitrogen in the soil

Nitrogen movement was studied with the installation of tensionics in the soil at 2 depths: 25 cm within the root zone and at 50 cm underneath the active root zone. For both, the first sampling was done before any fertilizer addition and the second one after the uniform application of nutrients to all treatments. This means that six of the samplings were conducted after the differential fertigation was started (Fig. 5). The mean concentrations for these six samples at 25 cm were as follows: T2C: 31.5 mg N/L, T2D: 56.3 mg N/L, T3C: 53 mg N/L and T3D: 143 mg N/L. The latter treatment showed the smallest decrease in concentration: 8 mg/L only. T2D and T3C presented similar decreases and final concentrations. T2C with the most important activity and uptake had the lowest mean concentration and a small amount of N loss as nitrate across the season (16 mg/L).

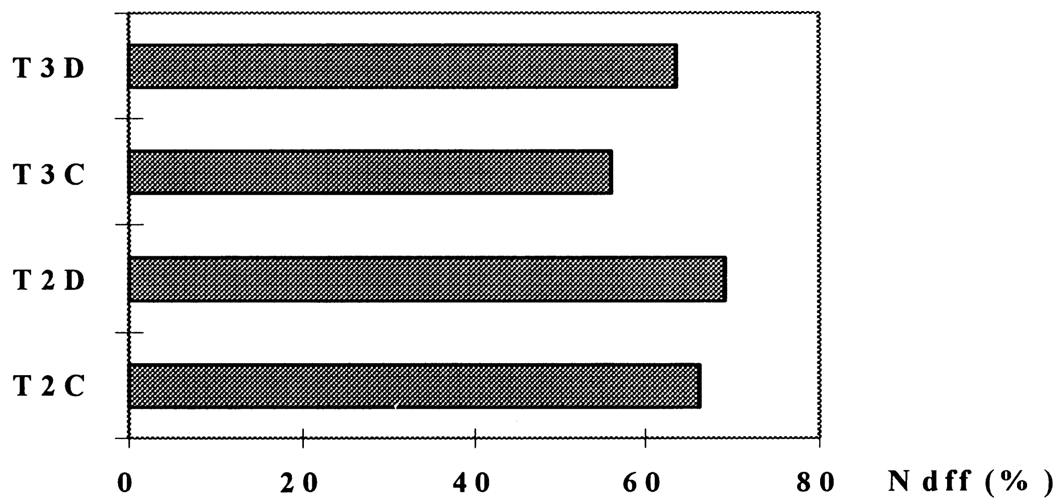

FIG. 3. Average values of nitrogen derived from fertilizers (%) by fruits and shoots of cucumber.

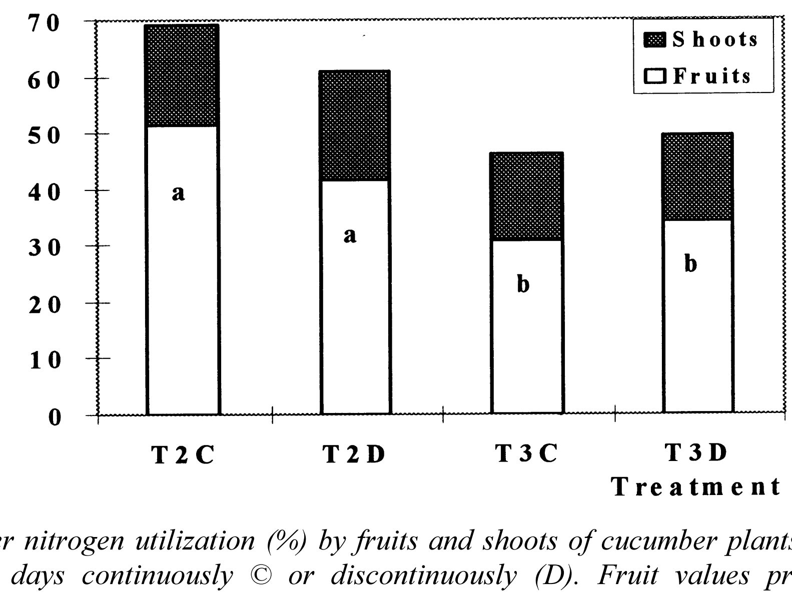

FIG. 4. Fertilizer nitrogen utilization (%) by fruits and shoots of cucumber plants irrigated every 2 (T2) or 3 (T3) days continuously © or discontinuously (D). Fruit values presented statistical differences.

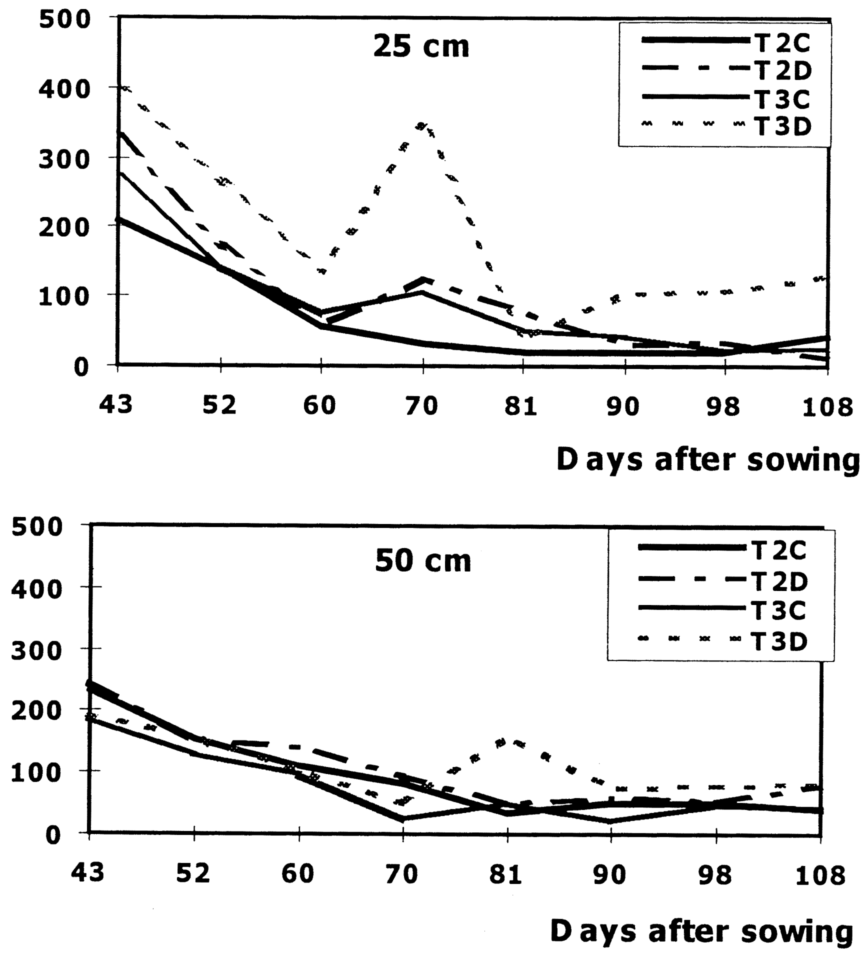

FIG. 5. Variations of nitrate–nitrogen (mg/L) concentrations in soil solutions extracted from tensionics placed at 25 cm and 50 cm in treratments irrigated every 2 (T2) or 3 (T3) days continuously (c) or discontinuously (D).

It was clear that T3D had the lowest activity, but the most favorable nitrifying conditions. This is shown by the small loss of nitrate at 50 cm (-22 mg/L) and the highest nitrate-N concentration (91.5 mg/L). At 50 cm, the concentrations were as follows: T2C: 61.2 mg/L, T2D: 79.5 mg/L and T3C: 47.8 mg/L. Each of these values could be considered as the mean concentration for the growing season. For each frequency, the values for the discontinuous treatments were higher than for the continuous modality.

Comparison between the two depths shows that the T2 treatments had higher concentrations at 50 cm, unlike the T3 treatments. This could be due, on one side, to the higher uptake in the T2 treatments, within the root zone, but also to a possible higher nitrifying activity, on the other side.

Another aspect of N was related to the determination of nitrate-N at three soil depths, at the beginning and at the end of the growing season (Table I). In comparison to the results from soils in the region, these concentrations were relatively low and were half of those found at 0–20 and 20–40 cm depths [6]. Such a moderate content of N was also demonstrated elsewhere. This is related to the proportion of N derived from the fertilizer (Ndff %).

At the end of the experiment, the nitrate content of the treatments T2D, T3C and T3D was significantly increased as compared to the beginning of the experiment (Table I). Within a depth of 0–40 cm, being the main zone of root activity, the soil volume occupied by the 3 plants/m^2, was close to

216 cm^3, or the equivalent of 54% of the total soil volume. Based on this observation, the nitrate-N accumulation was as follows: -0.36 g N/m^2 in T2C, + 1.82 g N/m^2 in T2D, +8.03 g N/m^2 in T3C and + 8.13 g N/m^2 in T3D. Once more, T3C showed a smaller N uptake as expressed by a higher accumulation in the root zone. Consequently, N losses following the growing season would be 4 times higher for the T3D treatment than for the T2D treatment. This higher N fertilizer utilization is in agreement with the dry matter production. On the other hand, the finding with the tensiometers also suggested a more active nitrification with the 3-day irrigation frequency. As for the balance, a very close correspondance was obtained between the difference between input and uptake and the nitrate-N accumulation in the soil (Table II). This allows to decide that the N losses were minimal for all treatments. This could be largely explained by the amount of nitrate accumulated in the soil.

These overall results are remarkable, considering the narrow separation between the treatments. The key to such significant differences within this narrow range could be the electrical conductivity of the fertigation solutions and of the soil. The electrical conductivity of the soil at the end of the experiment showed, as for the nitrate-N, significant differences in the 0–20 cm soil layer (Table III).

TABLE I. NITRATE-N CONCENTRATION (mg/kg dry soil) IN THE SOIL AT THE BEGINNING AND AT THE END OF THE EXPERIMENT, AT 3 DEPTHS. WITHIN EACH LINE, VALUES FOLLOWED BY THE SAME LETTER ARE STATISTICALLY NOT DIFFERENT

Soil depth (cm)	NO_3-N^- (mg/kg)				
	Beginning	End			
		T2C	T2D	T3C	T3D
0 –20	60.7 a	61.5 a	81.5 b	125.5 b	110.5 b
20–40	54.5 a	51 a	51 a	62 b	68 b
40–60	33.5	18	23	19	18

TABLE II. NITROGEN BALANCE IN TREATMENTS IRRIGATED EVERY TWO (T2) OR THREE (T3) DAYS ON A CONTINUOUS (C) OR DISCONTINUOUS (D) BASIS

Treatment	Nitrogen (g/m^2)			
	Input	Removal by plants	Input-Removal	NO_3^--N build-up (0–40 cm)
T2C	25.75	24.17	1.58	-0.36
T2D	25.75	20.39	5.36	+1.82
T3C	25.75	19.01	6.74	+8.03
T3D	25.75	17.92	7.83	+8.13

TABLE III. ELECTRICAL CONDUCTIVITY (dS/m) OF THE SOIL AT THE BEGINNING AND AT THE END OF THE EXPERIMENT, AT THREE DEPTHS. WITHIN THE LINE 0–20 cm, VALUES FOLLOWED BY THE SAME LETTER ARE STATISTICALLY NOT DIFFERENT

Soil depth (cm)	EC (dS/m)				
	Beginning	End			
		T2C	T2D	T3C	T3D
0 -20	2.19 a	2.40 a	3.87 b	3.77 b	3.75 b
20–40	1.92	1.80	2.25	2.70	2.50
40–60	2.07	1.07	1.30	1.44	1.62

The proportion of N derived from the fertilizers (%) varied between 54.76% and 69.86%. These values were relatively high under field conditions, confirming the moderate input of nutrients and suggesting a medium N status in the soil. With regard to the fertilizer N utilization, the treatments irrigated every two days gave higher results for the fruits, due to the dry matter production. However, the fate of some 30% of N fertilizers at best, and 46% at worst, remained unknown.

In general, the nitrate-N build-up in the soil was lower for the T2 treatments than for the T3 treatments, because of the higher fertilizer utilization and possibly better oxidizing conditions in the latter.

4. CONCLUSION

For this experiment, the length of the growing season was closer to that of the growers in springtime. The N input was based on previous results and could be considered as moderate but sufficient. Despite the narrow range that separated the irrigation frequencies (every 2 or 3 days) significant results were obtained as far as the plant performance is concerned. This included fresh fruit production, the number of fruits, the number of non-commercial fruits and shoots dry matter production. The best treatment was the continuous irrigation every two days (T2C). This could possibly be linked to the irrigation water having a relatively high electrical conductivity, with an increasing risk of salinity. Such background lead to an important fluctuation in salinity for all treatments, except the T2C receiving the most stable and frequent input.

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COMPARATIVE WATER AND N FERTILIZER UTILIZATION IN FERTIGATION v/s SOIL APPLICATION UNDER DRIP AND MACRO SPRINKLER SYSTEMS OF SPRING POTATOES UTILIZING ^{15}N IN CENTRAL BEQAA, LEBANON

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Abstract

The experiment aimed at studying the impact of type of fertilizer application and irrigation techniques on the yield parameters of spring potatoes by using ^{15}N. In 1997 and 1998, a potato crop (Spunta) was planted in a clayey soil in Tell Amara, Central Beqaa, in a randomized block design. It consisted of five treatments and four replicates. The goal of the research was to study the effect of three rates of N fertigation (N1 = 240, N2 = 360, N3 = 480 kg N/ha for 1997 and N1 = 120, N2 = 240, N3 = 360 kg N/ha for 1998) on potato performance and production, comparing full fertigation with conventional fertilizer application and irrigated with drip and macro sprinkler. Water demands and irrigation were scheduled according to the mean annual potential evapotranspiration in 1997 and Class A pan in 1998, and monitored by the neutron probe and tensiometers. The results show that, at harvest, both crops followed the same yield pattern. The highest tuber yield was obtained from N1 and the lowest from N3. These values were 58 ton/ha for 1997 and 32.5 ton/ha for the 1998 trial. The 1998 spring crop was more efficient in terms of N utilization. The reduction of N input in N1 resulted in 90% N-fertilizer recovery. In the treatment with soil N application, drip irrigation saved up to 50% of water and improved the efficiency of removed N. Starting from the 89th day after planting, sprinklers caused a significant difference in NO3- concentration leached beyond 60 cm depth. Thus, fertigation was superior with regard to fertilizer and water saving and it decreased the risk of N building up in the soil and shallow groundwater resulting in pollution.

1. INTRODUCTION

In Lebanon cash crops are fertilized by soil application of complex, low solubility fertilizers and irrigated by macrosprinklers. The average yields of most crops are relatively low: 40 ton/ha for citrus and 20–25 ton/ha for potato [1,2]. In 10 years, the total water consumption in Lebanon is expected to reach 3,400 million m^3 [3]. The average available surface and ground water is less than 300 million m^3 [4]. Nutrient and water use efficiency can be improved through fertigation with micro irrigation systems [5]. The efficient use of irrigation water and fertilizers is essential to keep food supply in balance with the increasing demand on environmentally sound practices [6]. Increasing crop production with the improvement of its quality and reduction in the cost is becoming a problem for the sustainability of agriculture in Lebanon. This implies increasing both fertilizer and water use efficiencies.

Such conditions also apply to potato, as an important cash crop in Lebanon. It is a major winter crop on the coastal area, and spring and summer crop in the Beqaa Valley. The area which is cultivated with potato in Lebanon is 14,580 ha [7], of which 67.4% is located in the Beqaa Valley.

The rates of fertilization and irrigation of cash crops in Lebanon are not based upon the results of local research and conclusions. In fact, farmers apply 1,700 kg/ha of compound NPK (300 kg N/ha) fertilizers split into two applications and irrigated for 8–12 hours/week with macro sprinklers, regardless of the crop development stage, weather conditions, the soil type and expected yield. This could result in overfertilization and excessive irrigation contributing to lower water and fertilizer use efficiency and possible ground water contamination by nitrate. The implementation of fertigation on potato is an actual and important issue to secure higher yields with better quality on an economically and environmentally safe ground. For these reasons, this study was conducted aiming at establishing the N demands, water and fertilizer use efficiencies of spring potato in the main growing region of the Beqaa valley, as affected by N input, methods of fertilizer application and irrigation technique.

2. MATERIALS AND METHODS

A field experiment involving the use of labelled N fertilizers with the heavy isotope ^{15}N and aiming at studying the impact of different rates of N on the yield of the Spunta H (Hettema) potato variety was undertaken. The trials were conducted on a non-calcareous clay, 0–2%, montmorillonitic Typic Xerorthent soil (Table I) at the National Institute for Agronomic Research (Tell-Amara station) in the Central Beqaa Valley, Lebanon, in the spring of 1997 and 1998. For both seasons, sowing was conducted in early May and tubers harvested towards the end of August.

TABLE I. SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

Location	Depth (cm)	pH (1:2.5)	EC (dS/m)	Clay	Silt (%)	Sand	O.M (%)	P (mg/kg)	K	Total N (%)
Tell-	0–20	8.0	0.44	42	32	25	1.2	28	360	0.147
Amara	20–40	7.9	0.44	42	32	25	1.1	28	360	0.147
Station	40–60	8.0	0.46	42	32	25	1.0	28	370	0.123

The practice of the Lebanese farmers consists of irrigating potatoes through macro sprinklers (nozzles 5/32 or 5/36 and discharge 1.6 m^3/hour), for 8 hours, once a week, between sowing and emergence. During the next fifteen days, the duration of irrigation is increased until 10 hours weekly to reach, in general, 12 hours/week during the rest of the season. So, Ncs (N control sprinkler) was fertilized similarly to Ncd (N control drip) but it was irrigated according to the practice of the farmers.

2. 1. Treatments

Irrigation was scheduled according to the mean annual potential evapotranspiration [8] in 1997 and Class A-pan in 1998. The crop fractions were applied according to [5].

The treatments of the 1997 trial consisted of 3 N application rates: N1 = 240 kg N/ha, N2 = 360 kg N/ha and N3 = 480 kg N/ha (Table II). Based on the results of the first year, the rates of N were reduced in the 1998 trial to become: N1 = 120, N2 = 240, N3 = 360 kg N/ha. For comparison of the two irrigation techniques, two control treatments were included in the study and both received the same N fertilization rate as N2 but as soil application. One of the treatments was irrigated with the macro sprinkler (Ncs), while the other was irrigated with a drip system (Ncd).

The concentrations of P and K were kept fixed in all treatments and were equivalent to 200 and 400 kg/ha, respectively. The design of both experiments was a RBD, with 5 blocks and 4 replicates. The dimensions of each plot were 4.5 × 9 m. In each plot 6 rows were planted at a density of 25 × 75 cm. i.e., a total of 216 plants/plot of which 144 plants were effective.

2. 2. Isotope studies

The use of labelled fertilizers provides a direct method for the evaluation of N and P uptake by different plant species [9]. In each plot, a small area (microplot) was designated for ^{15}N

application. Microplots or isotope plots usually cover the smallest possible area to obtain a representative sample for the estimation of the isotopic parameters [10]. Microplots, with an area of 1.125 m^2 each, consisting of 6 plants in 1997 and 1.5 m^2 and 8 plants in 1998, were chosen from the middle rows. Microplots were fertigated with ~1.5% ^{15}N atom excess, applied as ammonium sulfate. For data collection and estimation of N fertilizer recovery, only the protected plants were chosen: 2 in 1997 and 4 in 1998.

TABLE II. METHODS OF FERTILIZER APPLICATION AND IRRIGATION TECHNIQUES

Treatments	Irrigation system	Fertilizer application	N (kg/ha) 1997	N (kg/ha) 1998	P (kg/ha)	K (kg/ha)
Ncs	Macro Spray	Soil	360	240	200	400
Ncd	Drip	Soil	360	240	200	400
N1	Drip	Fertigation	240	120	200	400
N2	Drip	Fertigation	360	240	200	400
N3	Drip	Fertigation	480	360	200	400

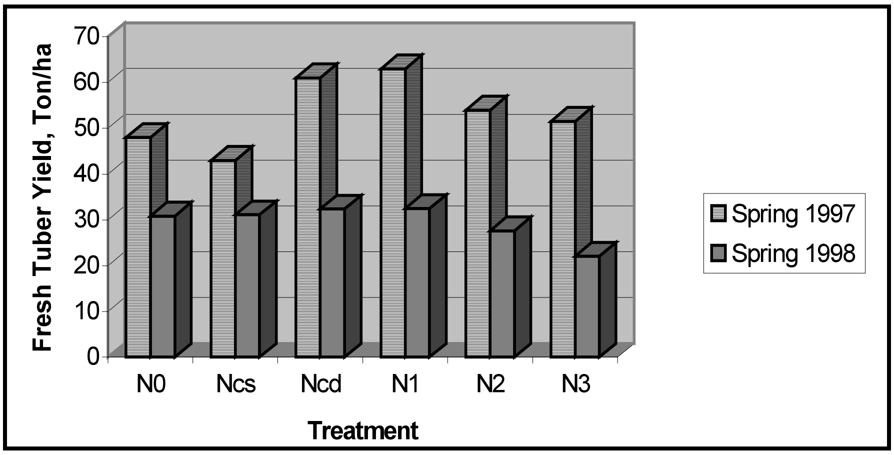

FIG. 1. Fresh tuber production at physiological maturity of fertigated spring potatoes in Central Beqaa, Lebanon.

3. RESULTS

3. 1. Tuber fresh yield

In both trials, the fresh tuber production at physiological maturity followed the same pattern (Fig. 1). However, no significant difference was among the treatments. In both cropping years, N1 and Ncd gave a slightly higher yield. This trend indicates the possibility of reducing the N input under potato in the Beqaa plain, where the built up of soil N could be mobilized and used as additional reserve, beside the N present in the irrigation water.

The results imply the possibility of a more efficient use of nutrients and water by fertigation or by a simple shift to localized irrigation techniques. Beside, as long as no significant increase of yield with higher inputs was obtained, there is a rational or a potential for decreasing the water and N doses applied to potatoes in the Beqaa Valley. This must help water saving, reducing the cost of production and preventing hazards related to the buildup of nutrients in the soil and their possible transfer to the groundwater.

3.2. Tuber size and specific gravity

The best commercial tubers were obtained by the lowest N input in both years (Table III), with the dominance of the elite category (>50% in 1997 and >40% in 1998).

As at maturity, this was influenced by the N fertilization rate. According to the results, a low N input reduced the life period of the plant and accelerated the maturity of the tubers, whereas high N levels had a delaying effect on plant senescence. However, the specific gravity values were not significantly affected by an increasing N level, suggesting a comparable level of tuber maturity. But, excess water could have resulted in a lower dry matter (DM) content, as it decreased by 2.2% in the treatment irrigated by sprinklers as compared to the drip system, in 1997 only (Table IV). The comparison of the mean DM and SG values of all treatments irrigated by drip with those values obtained from the macro sprinkler treatment demonstrates a possible trend between the irrigation practice and these important yield components.

TABLE III. DISTRIBUTION OF MARKETABLE TUBERS (% OF TOTAL)

Treatment	Ncd		N1		N2		N3	
	97	98	97	98	97	98	97	98
<4 cm	13.0	7.71	10.0	9.93	12.2	11.25	13.1	10.49
4–6 cm	36.0	52.85	32.5	45.74	41.2	51.76	33.8	49.22
>6 cm	51.0	39.44	57.5	44.33	46.6	36.99	53.1	40.29

TABLE IV. MEAN TUBER CHARACTERISTICS AS AFFECTED BY THE METHOD OF IRRIGATION

Characteristics	Drip		Sprinkler	
	1997	1998	1997	1998
Specific gravity	1.08	1.07	1.07	1.06
Dry matter (%)	20.2	16.65	18.0	16.25
Starch content (%)*	13.8	10.40	11.8	10.05

*: Conversion from specific gravity according to [11].

As reported in the literature, increased levels of N fertilizers results in a decreased dry matter and starch content [12,13,14]. The results show that these criteria did not lead to a significant difference with regard to the way of fertilizer application. However, the irrigation techniques and water amount revealed a trend of priority for the drip systems.

3.3. Dry matter production

With different N rates, ways of fertilizer application and irrigation techniques, the dry matter production showed a trend of decrease with the excess N input (Table V). For the same N rate and application, the drip irrigated treatments showed a priority in terms of dry matter accumulation in the tubers.

TABLE V. TUBER DRY MATTER PRODUCTION OF SPRING POTATOES (kg/ha) WITH DIFFERENT MANAGEMENT OF WATER AND NUTRIENT INPUTS

Treatment	N0	120 kg N/ha	240 kg N/ha	360 kg N/ha	480 kg N/ha	Ncs	Ncd
1997	9192	--	11788	9511	10149	7898	11072
1998	5022	5460	4506	3714	--	5059	5215

3.4. Interactions between water applied, consumed water and dry matter production

The amount of water applied by fertigation through the drip system was 497 mm (93.19 L/plant) for the 1997 spring potato and 495 mm (92.81 l/plant) for 1998 (Table VI). The treatment with the macro sprinkler system, widely practiced by Lebanese farmers, received 839 mm (157.3 L/plant) and 879 mm (164.81 L/plant) for 1997 and 1998, respectively. This result illustrates the possibility of water saving. As an intermediate phase towards full fertigation practices, the reliance of drip irrigation coupled with the same fertilizer application technique could be an alternative.

Efficiency of water application and use

With the expected future scarcity of water, it is crucially important to plan land use considering water availability and crop water consumption in close relation to farmers' income. A comparison between both irrigation systems shows an extremely higher water application for the production of one unit of dry matter with the sprinkler system as compared to the drip system (Fig. 2).

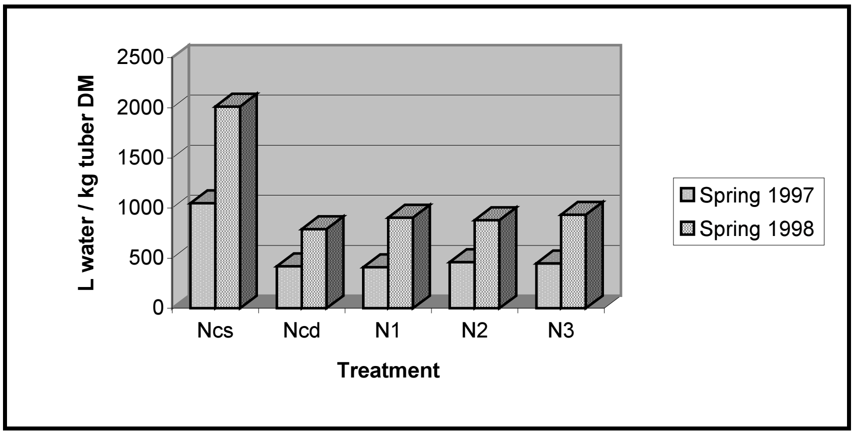

FIG. 2. Amount of applied water to produce one unit of consumable product for spring potato in Central Beqaa, Lebanon

Therefore, productivity was significantly higher for the latter. Consequently, more important water losses occur under the macro sprinkler system (Table VII).

Water saving to produce the same tuber dry matter of the spring crop varied about 100% in both trials. These results suggest a further saving on the recommended water input as this amount is far below the recommended value (750 mm) and actually applied amount (~840 mm) of water for the spring crop, according to the practice of farmers. This was a further improvement on previous research showing that the water demand of potatoes did not exceed 650 mm [15].

TABLE VI. WATER REQUIREMENTS OF SPRING POTATO IN CENTRAL BEQAA, LEBANON

Days After Sowing							Total (mm)
Spring	1–15	16–30	31–45	46–60	61–75	75–105	
Crop Fraction*							
	0.4	0.7	0.9	0.8	0.7	0.7	
Applied Water by Drip (l/plant)							
Spring 97	7.8	15.15	20.96	18.80	15.33	15.16	497.0
Spring 98	8.01	13.96	19.43	19.84	16.73	14.84	495.0
Applied Water by Sprinkler (l/plant)							
Spring 97	21.6	23.6	35.4	23.6	23.6	23.6	839.0
Spring 98	17.14	18.86	34.0	36.0	29.4	29.4	879.0

* [5]

TABLE VII. WATER APPLICATION AND CONSUMPTION (mm) BY POTATO IN THE 1998 SPRING SEASON IN CENTRAL BEQAA, LEBANON

Treatment	Applied Water	Effectively applied (ef) water	Consumed Water	Leached Water mm	Leached Water % from (ef)
Ncs	879	615	343.3	271.7	44.2
Ncd	495	445	404.5	40.5	9.1
N2	495	445	350.8	94,2	21.2

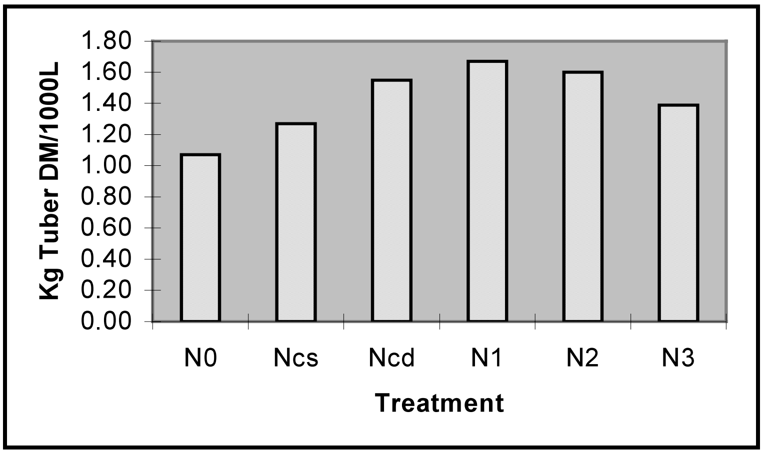

FIG. 3. Efficiency of consumed water per unit tuber dry matter production for spring potato in central Beqaa, Lebanon (1998).

However, calculation of the efficiency in relation to the consumed amount of water revealed the least consumed water per unit dry matter production for the lowest N input in 1998. The highest consumption was observed for N0 (Fig. 3). It seems that in the absence of N, the crop transpiration increased. Within the current soil fertility background and the nitrate content in the irrigation water, a more efficient use of consumed water was noticed for the lowest N application rate (N1).

3.5. Aspects of nitrogen use efficiency

3.5.1. Nitrogen content

The total N content in the potato plants at physiological maturity showed significant differences only for the aboveground parts of the 1997 season (Table VIII).

TABLE VIII. TOTAL N CONCENTRATION (% DRY MATTER) IN POTATO AT PHYSIOLOGICAL MATURITY

Treatments	Foliage		Tubers	
	1997	1998	1997	1998
Ncs	2.53 b	4.89	1.07	2.48
Ncd	2.93 a	3.64	1.37	2.02
N1	3.35 a	3.60	1.53	1.09
N2	3.61 a	4.34	1.61	2.19
N3	3.99 c	4.59	1.52	2.21

Means within a column followed by the same letters are not statistically different at the 5% level.

The excess N input (N3 = 480 kg N/ha, in 1997) resulted in a different accumulation of N in the above-ground parts and not in the tuber yield, causing a delayed maturity in N3 with an important vegetative growth. This fact could have slowed down the translocation of nutrients to the sink. However, with a lower fresh tuber production, the 1998 trial showed an increase in N concentrations in both parts of the potato crop.

A lower N concentration was noticed in Ncs of the 1997 trial, due to reduced water use efficiency following the overirrigation by the macro sprinkler system. As a possible consequence, plants in Ncs had a vigorous growth reflected by the dilution effect on the N concentration in the aboveground parts. This resulted in an N concentration as low in Ncs as 0.45% in the consumable product with, however, no significant difference in comparison with N2. Such an effect was confirmed in the 1998 trial where 240 kg N/ha for Ncs presented a reverse picture.

Consequently, the potato cropping system with 360 kg N/ha applied to the soil and irrigated with the macro sprinkler system may only increase the cost of production. Considering the current land use and practices at the farmers' level, a relatively low efficiency of water and fertilizers might result in a low net return. This could threaten the sustainability of agriculture in Lebanon.

3.5.2. Fertilizer N utilization

With equal amounts of nutrients, N2 and Ncd were more efficient than Ncs (Tables IX and X). The amount of water applied with the drip was 44% less than that applied with the macro sprinkler (Table VII), confirming once more the efficiency of the localized system in controlling water and nutrient supply. Moreover, since it can efficiently be applied in all types of areas - undulating terrain, rolling topography, hilly areas, shallow soils and water scarce areas – a concerted policy should be formulated to increase the area under drip irrigation by taking into account both the availability of irrigation water and the demographic expansion [16].

TABLE IX. NITROGEN REMOVAL AND RECOVERY BY THE OVER GROUND PARTS OF SPRING POTATO (Mean values from 4 replicates)

Cropping System	Treatment	DM yield (kg/ha)	N yield (kg/ha)	Ndff %	Fertilizer N yield (kg/ha)	% Fertilizer N Utilization*
	Ncs	3924.5a	109.9a	38.70a	42.3a	11.8a
	Ncd	4250.4a	128.0a	49.20a	63.3a	17.6a
Spring 1997	N1	2445.5a	081.2a	38.51a	31.3b	13.0a
	N2	2517.5a	089.2a	44.30a	38.1a	10.6a
	N3	2152.8a	087.3a	50.80a	44.9a	09.4a
	Ncs	3609.5	183.3a	52.7a	92.8	38.7a
	Ncd	2906.0	107.2ab	28.9b	34.0	14.2b
Spring 1998	N1	2487.7	88.15ab	63.2a	55.6	46.3a
	N2	2835.8	123.3ab	57.4a	68.8	28.7ab
	N3	2896.9	135.1ab	62.1a	86.4	24.0ab

- Within each cropping season, values followed by the same letter have no statistically significant difference.
*- %Fertilizer N Utilization is the ratio of fertilizer N yield to the N rate of application.
- %Ndff: N derived from fertilizer.

TABLE X. NITROGEN UPTAKE AND RECOVERY BY POTATO TUBERS.

Cropping System	Treatment	DM yield (kg/ha)	N yield (kg/ha)	Ndff %	Fertilizer N yield (kg/ha)	% Fertilizer N Utilization*
	Ncs	7979.2	111.0	38.2a	42.5	11.76
	Ncd	8266.6	108.3	46.5a	51.6	14.32
Spring 1997	N1	7076.6	108.8	23.5b	26.6	11.09
	N2	8387.9	135.0	41.5a	56.0	15.55
	N3	5512.6	081.5	50.1a	40.9	08.51
	Ncs	4364.8	106.2	48.1a	50.5ab	21.1b
	Ncd	6260.0	122.3	29.5b	35.8b	15.0b
Spring 1998	N1	5474.6	109.3	50.8a	52.6ab	43.9a
	N2	5617.8	122.1	51.8a	63.7a	26.5b
	N3	5308.4	116.8	55.8a	64.3a	17.9b

* % Fertilizer N Utilization is the ratio of fertilizer N yield to the N rate application.
- % Ndff: N derived from fertilizer

On the other hand, the N1 (120 kg N/ha) treatment in the 1998 trial appeared to be more attractive than both treatments receiving the middle level of N (Ncs, Ncd and N2) in terms of fertilizer utilization. This rate was also more suitable from the economical as well as the public health and environmental point of view. It is worth mentioning the low fertilizer N yield and fertilizer N utilization of the Ncd treatment in the 1998 trial. It seems that applying the full N dose (240 kg N/ha) to the soil resulted in an expansive use of soil N with higher water consumption.

Thus, in soils containing enough residual N to ensure, beside the N present in water, a reasonable yield, research should aim for the lowest effective rates of N maintaining the soil fertility and producing a high yield with appropriate quality. In this study, the 1998 spring crop was more efficient than the 1997 one in terms of N use, as clearly shown by the high fertilizer N recovery (90%) with the lowest N rate. Elsewhere, it has been demonstrated that the potato crop can make successful use of the soil reservoir: up to 70% of the total removed N, even with the application of both ammonium and nitrate fertilizers [17]. Taking into consideration other N sources, recommendations for the use of N carriers should be oriented and adapted for meeting both crop and site requirements.

Trials run in Lebanon showed that to get a modest yield of 28 tons/ha, an amount of 100 kg N/ha was necessary. An additional tuber yield of 6 tons/ha required an increase in N input of 20%, without any modification in the applied P and K [18]. An excess rate of fertilizer-N did not significantly contribute to higher yields and negatively affected some tuber qualities [14]. In many temperate areas, N is the nutrient the most likely to be limiting on most soil types and in most seasons [19]. Concerning the soils of the Middle East Region the available N, as ammonium and nitrate, is so low that soils easily respond to N fertilization [20]. A tuber yield of 50 ton/ha requires as much as 250 kg N/ha as total N uptake in both tuber and plant vegetative parts [21]. Potato yields of up to 70 ton/ha could be obtained under irrigated conditions and an N application of 300 kg N/ha would be economically justifiable [22].

3.6. Nitrate in the soil and soil solution

With the use of modern irrigation, fertigation became a promising means for maintaining N concentrations in the soil within the rooting zone, throughout the growing period, at desirable levels, without undue losses by leaching [23]. This is especially important with regard to possible nitrate leaching and contamination of the ground water. Indeed, increasing rates of N results in higher soil nitrate residues. This is in agreement with other results [14]. The fluctuation of NO_3^- was affected not only by the rate of N application, but also by the way of fertilizer application and irrigation techniques. With drip irrigation NO_3^- was maintained within the root zones while it was intensively leached with macro sprinkler irrigation (Table XI).

Study of the nitrate levels in the soil solution by tensionics gave, starting from the 89th day after planting, a significant difference between the NO_3^- leached beyond the root zone, under macro sprinkler irrigation than from the fertigated and drip irrigated treatments (Fig. 4). The NO_3^- concentration in these treatments, between 60 and 80 cm depth, did not present a significant fluctuation around the values noticed in N0 and N1.

This could result in a higher yield and better quality products than by conventional irrigation means [24]. The NO_3^- accumulation or leaching is important not only for the quality of the consumed product (Table XII), but also for the quality of soils and underground water.

4. DISCUSSION AND CONCLUSION

Trials with fertigation of potato demonstrated that a constant N-concentration in the final solution provided a better yield [25]. The uptake efficiency of mineral nutrients, notably N, was increased substantially through fertigation [23, 26]). This is particularly relevant to the nitrate form of N, which is not retained in the soil and therefore moves with other soluble salts to the wetted front. This mobility can best be overcome by application of nitrate-N with every irrigation at a concentration adequate to satisfy the crop requirement for N from one irrigation to the other [27]. In addition, fertigation provides the means to monitor and change the ratio NO_3^-/NH_4^+ during the season, which could avoid environmental problems associated with the contamination of groundwater.

TABLE XI. RESIDUAL SOIL NO_3^- (mg/kg dry soil) AS INFLUENCED BY THE TREATMENTS.

Final NO_3^- mg/kg dry soil							
Soil Depth (cm)	Initial NO_3^-	N0	N1 240 kg N/ha	N2 360 kg N/ha	N3 480 kg N/ha	Ncd	Ncs
1997							
0–20	11	28.85a	47.31a	95.45a	121.89a	35.94a	32.29a
20–40	13.5	11.91a	35.15a	47.5a	54.47a	20.66a	59.39a
40–60	11.5	11.59c	16.16b	26.6b	34.55b	31.02b	41.74a
1998							
Soil Depth (cm)	Initial NO_3^-	N0	N1 120 kg N/ha	N2 240 kg N/ha	N3 360 kg N/ha	Ncd	Ncs
0–20	8.23	18.22b	16.30b	82.36a	88.71a	34.77b	26.48b
20–40	10.56	8.68b	12.13b	21.09b	91.47a	12.93b	20.61b
40–60	8.66	8.45b	10.10b	14.84b	28.82a	7.15b	12.54b

- Values at the same depth, followed by the same letters are not significantly different at 5% level.

TABLE XII. MEAN NO_3^- CONTENT (mg/kg fresh tuber) IN FRESH POTATO TUBERS

Year	N0	120 kg N/ha	240 kg N/ha	360 kg N/ha	480 kg N/ha	Ncd	Ncs
1997	62.14b	--	130.2a	144.6a	158.7a	126.7a	107.6a
1998	55.13b	111.5ab	178.4a	198.2a	--	112.3ab	177.2a

Values followed by the same letters are not significantly different at 5% level.

The superiority of fertigation over other practices was clear from the yield and efficiency of N and water use at the lowest rate of N application. It is well understood that owing to a high initial investment, most of the farmers are reluctant to adopt the drip method of irrigation for crops, which give a smaller remuneration [16]. However, given the high savings in water in our experiments (up to 50%), one of the future tasks of the extension programs would be the shifting to modern irrigation techniques with the introduction of subsidy on drip materials that could be produced locally. But, pressurized water must be provided to farmers with a water meter at the gate of the farm at reasonable prices. This should encourage the economic and efficient use of water.

Even the simple practice of soil fertilizer application coupled with the improvement of water management through drip in Ncd reduced losses associated with an overirrigation and it increased the profit from the N-fertilizer, removed N and consumed water. Given other sources of N (soil reservoir, water), the lowering of N input under potato from 300 to 120 kg N/ha would be beneficial for the Lebanese Farmers, as it provided 90% of fertilizer N utilization with no significant impact on tuber yield and lower NO_3^- leaching hazards. By reducing the cost of production, Lebanese products would be competitive on the regional market.

For these reasons, fertigation of spring potato in Central Beqaa, Lebanon, is a promising perspective allowing a more efficient and thus economic use of inputs, water and fertilizer savings, reducing the cost of production and causing less potential risk hazards for the soil and groundwater pollution with nitrate.

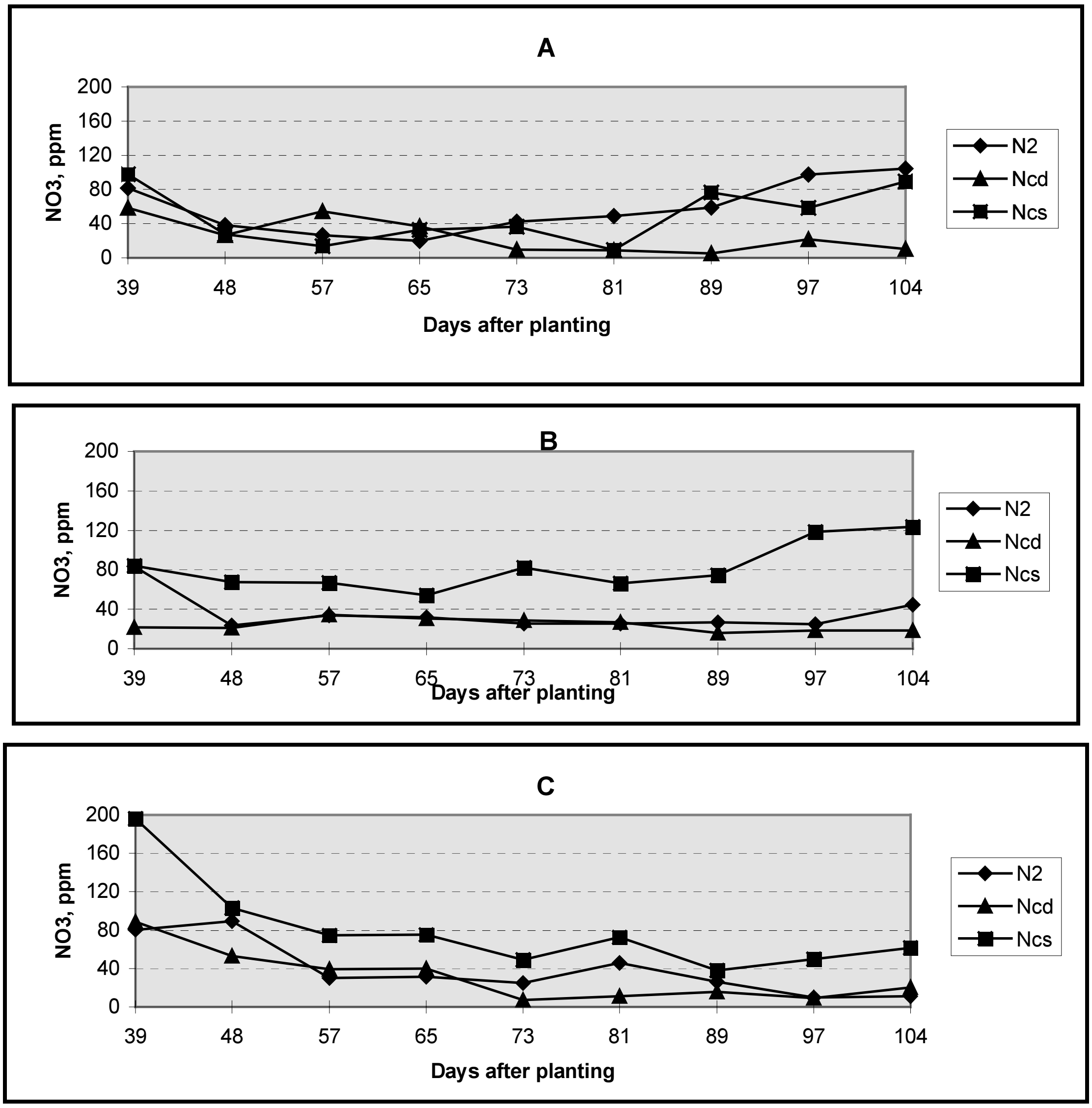

FIG. 4. Average concentration of NO_3^- in the soil solution measured by tensionics placed at different depths: (A) -40 cm, (B) -60 cm and (C) -80 cm.

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CROP MODELLING AND WATER USE EFFICIENCY OF PROTECTED CUCUMBER

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Abstract

Crop modelling is considered an essential tool of planning. The automation of irrigation scheduling using crop models would contribute to an optimisation of water and fertiliser use of protected crops. To achieve this purpose, two experiments were carried. The first one aimed at determining water requirements and irrigation scheduling using climatic data. The second experiment was to establish the influence of irrigation interval and fertigation regime on water use efficiency. The results gave a simple model for the determination of the water requirements of protected cucumber by the use of climatic data: **ETc = K* Ep.** K and Ep are calculated using climatic data outside the greenhouse. As for water use efficiency, the second experiment highlighted the fact that a high frequency and continuous feeding are highly recommended for maximising yield.

1. INTRODUCTION

Crop growth and production are the results of complex processes relating plants to their physical environment in the soil-plant-atmosphere continuum.

Classical agronomic approaches of crop responses to water were largely based on empirical experiments whereby yield is related to water (or water and other related inputs) applied as an independent variable [1]. When the total quantity per season is considered, typical "macro" production functions are generated [2]. When optimal timing and depth of irrigation is considered, "micro" water production functions are obtained. As such, response patterns are identified, simplicity is maintained, but explanation for such a response may remain unclear [1].

In general terms, a "crop response function", or preferably an "engineering production function" [3], is wanted to proceed towards the solution of the optimisation study. Consequently, crop modelling is considered as an essential tool of planning, management, and environmental impact assessment, scaling up and down between the farm (irrigation scheduling, productivity and economic evaluation) and the region (policy decision making, resource management).

Production in greenhouses has a higher efficiency of water use that might be improved further by a greater possibility of environmental, cultural practices and management.

Transpiration of greenhouse crops is one of the processes one would really like to control. This is due to two quite different and sometimes contradictory considerations. One is that crop production is related to water consumption [4]. The other has more to do with the saving of energy [5] . In fact, the application of energy saving devices (as double cover, thermal screens or reduced air exchanges), results in a lower rate of vapour removal, and a higher ambient humidity. Consequently, whatever the rationale for either increasing or reducing the transpiration rate of a crop by means of manipulating the greenhouse climate or the management of water and nutrients requirements of the crop, the relationship between these factors should be accurately known.

Previous studies in Lebanon determined the water and nutrient requirements of protected cucumber [6,7,8,9]. In addition, a simple method was established on a large scale for irrigation scheduling for different protected crops based on climatic data outside the greenhouse [10]. The study was completed by the determination of the actual evapotranspiration of cucumber (ETc) through a coefficient (K) and the evaporation from the small pan (Ep) [8]. The coefficient (K) was calculated as a function of days after sowing (DAS).

$$\mathbf{ETc = K^* \, Ep}$$

By changing the season, the plant growth varies according to the climate and consequently K will change. Therefore, it will be interesting to determine K as a function of plant growth (leaf area index "LAI" or plant height).

For a further saving in water use of protected cucumber, two experiments were carried out: the first one aiming to determine water requirements and irrigation scheduling using climatic data; the second experiment was to establish the influence of irrigation interval and the fertigation regime on the water use efficiency.

2. MATERIALS AND METHODS

The first experiment was run to determine, using air temperature outside greenhouses, plant growth of protected cucumber in terms of plant height and leaf area index. The leaf area index (LAI) as well as plant height were measured every 3 days. LAI was determined using a non-destructive method described by Parceveaux and Massin 1970. These measurements will serve to the determination of "K" factor relating the evaporation of small blue pans to the actual evapotranspiration of the crop. The work was executed starting from October 1997 till May 1998 (2 different periods of plantation, cycle I and cycle II).

Based on 250 mm of water requirements for cucumber, another experiment was done to highlight the influence of irrigation interval (2 vs. 3 days) and of fertigation regime (continuous vs. discontinuous feeding) on water use efficiency of protected cucumber. The experiment lasted from April to July 1998.

For this purpose, 4 treatments: T_2C, T_2D, T_3C & T_3D with 5 replicates were distributed in a block randomised system. Irrigation was scheduled according to the evaporation of a small blue pan (Ep) and a coefficient K depending on days after sowing (DAS).

A neutron probe determined the water consumption of the plants. Plant water status was characterised by the measurement of predawn leaf water potential using a pressure chamber [11]. Water potential in the soil was followed by tensiometers installed at 25 and 50 cm.

3. RESULTS AND DISCUSSION

3.1. Modelling of cucumber growth

Drawing the values of plant height (H) and LAI measured at two periods (Fig. 1), we can conclude that the plant rate of growth varied according to the season. Consequently, for the same day after sowing (DAS), cucumber plants had shown different values of H and LAI according to the season.

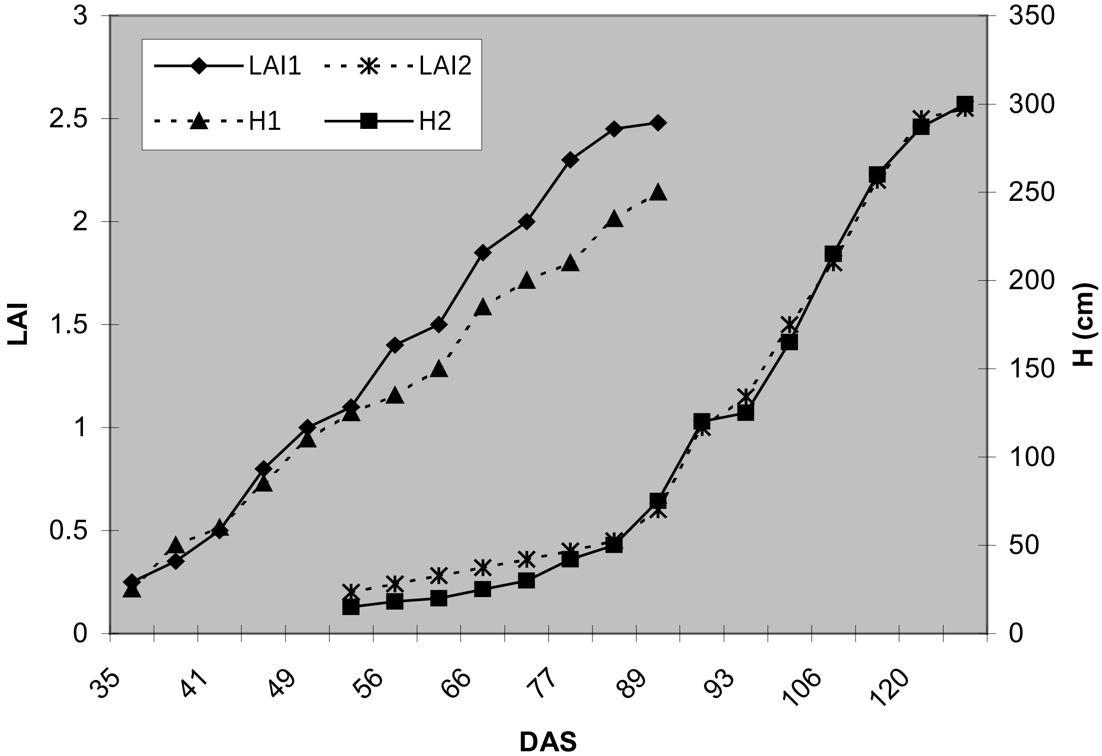

Figure 1. Influence of the season on the growth of protected cucumber.

While modelling H and LAI as a function of DAS, different equations were obtained:

$H_1 = 4*DAS – 93$ $\qquad$ $LAI_1 = 0{,}04*DAS – 1{,}14$

$H_2 = 4{,}8*DAS – 303$ $\qquad$ $LAI_2 = 0{,}04*DAS – 2{,}86$

However, LAI was related to H independently of the season:

$LAI_1= 0{,}0093*H$ $\qquad$ $LAI_2= 0{,}0086*H$

This result is in harmony with Yang et al. (1990) who found the following equation:

$LAI = 0{,}0089*H - 0{,}0965$

According to several authors, for the same level of water and nutrients in the soil, plant growth is a function of the cumulative value of temperature. Therefore, we determined LAI and H as a function of Σ(T) for the respective period.

The correlation showed similar equations regardless of the season:

$H_1 = 0{,}21*\Sigma(T) – 139$ $\qquad$ $LAI_1 = 0{,}0023*\Sigma(T) – 1{,}6938$

$H_2 = 0{,}24*\Sigma(T) – 216$ $\qquad$ $LAI_2 = 0{,}0022*\Sigma(T) – 1{,}93$

Combining the values of H and LAI of the 2 seasons, we obtain:

$LAI = 0{,}002*\Sigma(T) – 1{,}56$ $\qquad$ $H = 0{,}21*\Sigma(T) – 159$

In a previous study (Metri, 1997)[8], K was determined as a function of H:

$$\mathbf{K = 0{,}3153*Log (H) – 0{,}3851}$$

Replacing K with its value in the previous equation:

$$\mathbf{K = 0{,}3153*Log (0{,}21*\Sigma(T) – 159) – 0{,}3851}$$

So K will be determined by the cumulative value of temperature of the growing period. This model is supposed to be valid for all growing seasons.

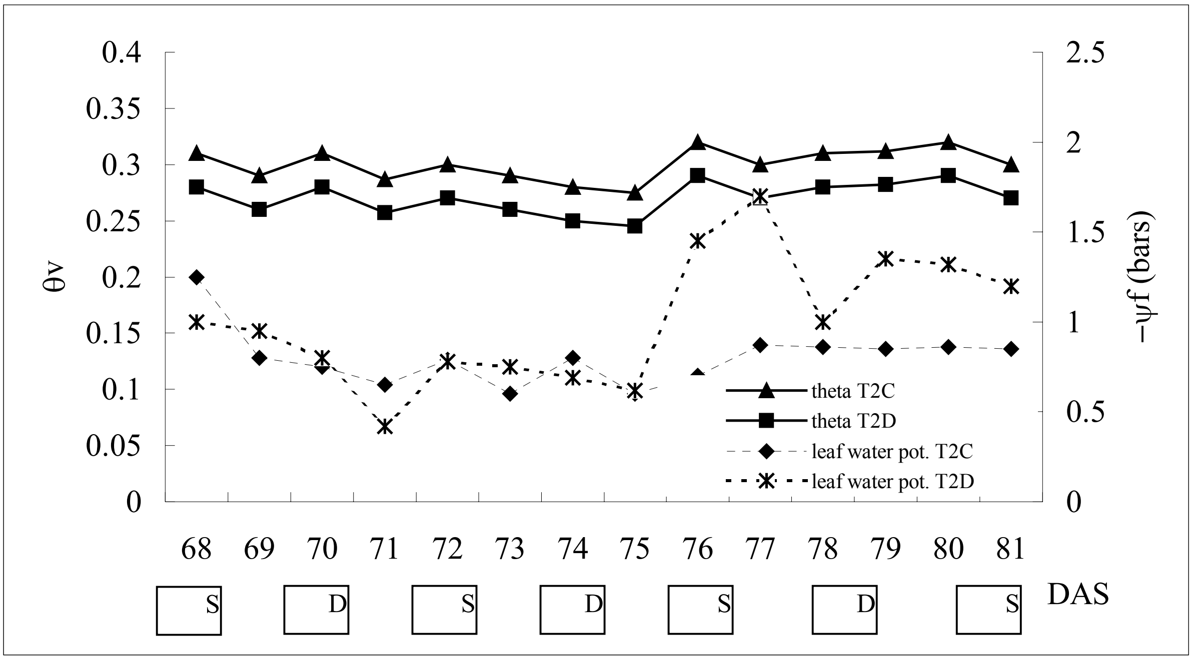

Figure 2. Evolution of predawn leaf water potential and water content for the treatments T2C and T2D.

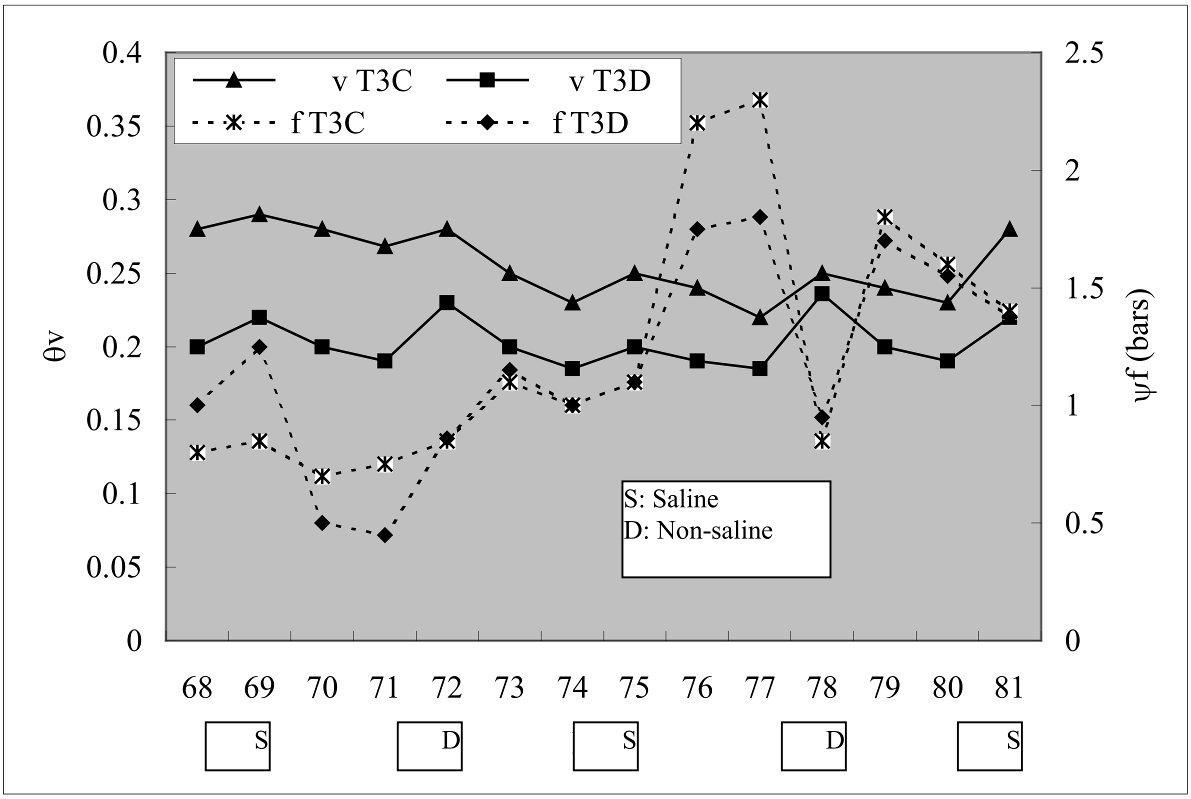

Figure 3. Evolution of predawn leaf water potential and water content for the treatments T3C and T3D.

3.2. Water use efficiency of protected cucumber

3.2.1. Leaf water potential

The predawn leaf water potential of the 4 treatments was measured during 14 days (68 till 81 DAS). The values obtained are drawn with the variation of water content in the soil for T2C and T2D (Fig. 2) as well as for T3C and T3D (Fig. 3).

3.2.1.1. Effect of fertigation regime:

The effect of fertigation regime was translated in a fluctuation of predawn leaf water potential (ψ_f) of the discontinuous treatments between an irrigation with fertilisers (S) and irrigation with water (D). The difference was reduced mainly during the period "68–73 DAS" which was characterised by a low climatic demand. In the following period, "74–81 DAS", the climatic demand increased and the difference was accentuated. (ψ_f) was relatively lower in the treatments with continuous feeding than in the treatments of the discontinuous regime due to higher fluctuation of salinity in the soil.

3.2.1.2. Effect of irrigation frequency

As for the fertigation regime, the predawn leaf water potential (ψ_f) was affected. Treatments with a high frequency of irrigation (T2) maintained a lower (ψ_f) with respect to treatments with low irrigation frequency (T3). This shows the effect of irrigation frequency on the plant water status with the variation of water content in the soil.

3.2.2. Leaf Area Index (LAI)

The leaf area index (LAI) was measured 4 times for all treatments: on the 53, 77, 97, 118 DAS. According to the values obtained **(**Table I**),** the irrigation frequency and fertigation regime nfluenced the leaf growth. LAI of treatments with high frequency of irrigation was positively affected as well as treatments with continuous feeding. This result sounds in harmony with the trend of leaf water potential discussed in the previous paragraph.

3.2.3. – Water consumption

Water consumption measured by a neutron probe showed significant differences among treatments (Table II).

As a consequent of leaf water potential and LAI, water consumption varied accordingly with a maximum value for T_2C and low values for T_3C and T_3D.

3.2.4. Yield

Yield in terms of fresh fruits was largely affected by the irrigation frequency and fertigation regime **(**Table III**)**. The treatments T2 showed a higher yield than the treatments T3 due to lower stress. Discontinuous feeding affects negatively the yield even within treatments with a high irrigation frequency (T2D).

3.2.5. Water use efficiency (WUE)

Water use efficiency is the ratio between yield and water consumption during the growing period. Treatments with low irrigation frequency showed higher WUE (TABLE IV). Although, the difference between treatments was non-significant.

TABLE I. LEAF AREA INDEX (LAI) OF DIFFERENT TREATMENTS

DAS	***T2C***	***T2D***	***T3C***	***T3D***
53	2.3	2.14	2.27	2.09
77	3.49	3.19	3.42	2.9
97	4.09	3.65	3.76	3.3
118	4.46	4.19	4.22	3.86

TABLE II. WATER CONSUMPTION OF THE DIFFERENT TREATMENTS

Treatment	T2C	T2D	T3C	T3D
Quantity (mm)	223.08a	178.56ab	131.33b	130.65b

Threshold of significance of 5%.

TABLE III. RELATIVE YIELD OF THE DIFFERENT TREATMENTS

Treatment	T2C	T2D	T3C	T3C
Yield (kg)	492.52 a	396.71 ab	390.13 b	348.15 b

Threshold of significance of 5%.

TABLE IV. WATER USE EFFICIENCY OF THE DIFFERENT TREATMENTS

Treatment	T2C	T2D	T3C	T3D
Efficiency (kg/l)	0.08a	0.08a	0.12a	0.11a

Threshold of significance of 5%.

3.2.6. Relationship between water consumption and yield

To establish this relationship, the following equation was used:

$$\left(1-\frac{Ya}{Ym}\right)=Ky\left(1-\frac{ETa}{ETm}\right)$$

With

Ya	actual harvested yield	Ym	maximal harvested yield
Ky	yield response factor	ETa	actual evapotranspiration.
ETm	maximum evapotranspiration.		

The result of the combination of the different values of water consumption and yield gave the following equation:

$$\left(1-\frac{Ya}{Ym}\right)=0.9155*\left(1-\frac{ETa}{ETm}\right)$$

4. CONCLUSION AND PERSPECTIVE

These experiments were a continuation of previous studies in order to improve water use in agriculture in general and to protect crops in particular.

The first experiment allowed the establishment of the factor K as a function of climatic data. The automation of irrigation is therefore possible by the connection with a weather station.

The second one highlighted the effect of irrigation frequency and fertigation regime on the yield and WUE of protected cucumber. A high frequency and continuous feeding are highly recommended for maximising yield. Low frequency and discontinuous feeding increase the WUE but not significantly.

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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	Leaf			Shoot			Fruit		
	kg/plot	N	P	K	N	P	K	N	P	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
	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

COMPARATIVE STUDY OF NITROGEN FERTILIZER USE EFFICIENCY OF COTTON GROWN UNDER CONVENTIONAL AND FERTIGATION PRACTICES USING ^{15}N METHODOLOGY

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Abstract

Nitrogen fertilization and irrigation methods are the key factors of yield increase. With proper management of these two factors a good production and protection of the environment could be attained at the same time. Field experiments were carried out at Hama (Tezeen's Agricultural Research Station) for four consecutive years 1995–1998. The objectives of this study were: Assessment of nitrogen fertilizer use efficiency (NFUE) under conventional and fertigation practices; Nitrogen requirements of cotton crop grown under fertigation practices: Comparative study of water use efficiency (WUE), and seed cotton yield of cotton crop grown under conventional and drip irrigation. Treatments consisted of five nitrogen rates for the fertigated cotton crop (0, 60, 120, 180 and 240 kg N ha^{-1}). While of the surface irrigated cotton treatment only one recommended rate by MAAR was applied (180 kg N ha^{-1}). Irrigation methods and N treatments were arranged in RBD. The soil water content and available soil nitrogen were monitored according to the standard procedures. The results revealed that fertigation of cotton under the given circumstances improved water use efficiency, nitrogen use efficiency, seed cotton yield, dry matter production, earliness and in some cases lint properties. Under fertigation practices 35–55% of the irrigation water was saved in comparison with surface irrigated cotton grown under the same condition. The seed cotton yield was increased by more than 50% relatively to the surface irrigated cotton. Furthermore, water use efficiency of the fertigated cotton was increased by almost 90 %.

1. INTRODUCTION

Fertigation is the precise application of irrigation water and plant nutrients through the irrigation system in order to match the current demand of the crop being nourished and irrigated. It has been recently introduced in the Syrian Arab Republic and would be a promising practice to the most economical crops such as cotton, potatoes, tomatoes and other vegetable crops grown in greenhouses. Advantages of fertigation are the minimal losses of water and plant nutrients [1,2,3,] and improved fertilizer use efficiency [4,5]. It supplies the plant nutrients directly to the root zone and therefore, optimizing the nutrient balance in the soil [2]. Minimizing the use of soil as a storage reservoir for nutrient and water leads to less nutrient fixation and losses by either leaching and/or volatilization [6]. It provides flexibility in timing the fertilizer application in relation to crop current demand [2], improving the yield and water use efficiency [7]. Fertigation seems to be the best available technique to balance water and nutrient supply for maximum cotton yield and other economical crops.

Drip irrigation is a promising practice in the arid and semi-arid zones where water is very scarce and costly. Water use efficiency must be an important economic consideration in order to benefit from the fewly available water resources and to reduce the cost of pumping. It has been extensively used on cotton [3,7,8,9,10,11,12,13]. In most cases, it improved cotton yield and/or water and fertilizer use efficiency. Smith et al. [9] reported a large increase in cotton yield grown under drip irrigation, and in other cases experiments showed that drip irrigation did not increase cotton yield in relatively to well managed furrow irrigated cotton [14,15].

Therefore, fertigation seems to be an effective means to control quantity, timing and placement of irrigation water and fertilizers. Yet, in the Syrian Arab Republic no sufficient information is available, for cotton and most other crops concerning fertilizer application rate, timing, irrigation scheduling, form of fertilizers, crop response in terms of quality and quantity, installation and maintenance.

The objectives of this study were as follows:

1. Assessment of nitrogen fertilizer use efficiency (NFUE) under conventional and fertigation practices.
2. Nitrogen requirements of cotton crop grown under fertigation practices.
3. Comparative study of water use efficiency (WUE) of cotton crop grown under conventional and drip irrigation.

2. MATERIALS AND METHODS

This study was conducted at the Tezeen's Agricultural Research Station of the Ministry of Agriculture and Agrarian Reform (MAAR), Irrigation Directorate, near Hama, (36.45E, 35.8N) in 1995, 1996, 1997 and 1998. The experimental site was planted with unfertilized maize as a previous crop in order to deplete as much as possible the soil available nitrogen, and to reduce field variability. The soil was clayey throughout the soil profile (>60% clay). Some selected soil properties are shown in Table I

TABLE I. SOME SELECTED SOIL CHEMICAL AND PHYSICAL PROPERTIES, 1995

Depth	pH	EC	Avai P	Ca-CO_3	OM%		CEC	Exchangeable Cations				Mechanical analysis		
cm	1: 2.5	dSm^{-1}	ppm	%	Bp[1]	Ah[2]	meq 100^{-1}	meq/100 g soil				sand	silt	clay
0–25	8	0.36	13.8	7.4	1.1	0.79	35.5	1.3	21.0	1.8	0.07	10	27	63
25–50	8	0.22	7.3	7.1	0.79	0.66	35.8	1.2	21.1	1.6	0.04	12	24	64
50–75	7.9	0.20	5.8	6.2	0.56	0.56	36.0	1.3	22.7	2.0	0.04	12	22	66
75–100	7.9	0.22	6.3	4.8	0.42	0.53	37.0	1.3	22.7	1.1	0.05	12	20	68

Cotton seeds (Aleppo 33/1) were hand-planted on April 10, 1995, 1996, 1997 and 1998. After all early season cultivation was completed; the fertigation system was installed on the surface of the appropriate experimental units. Irrigation was initiated on April 11, 1995, 1996, 1997 and 1998. Cotton was irrigated when the moisture in the upper 45.0 cm reached 80% of the field capacity (F.C) until peak flowering. Otherwise, the effective root depth was 75.0 cm until the end of the growth season for 1995. Since 1996 and due to the relatively high amount of irrigation water applied the effective root depths were changed to 30.0 cm from planting until peak flowering and 60.0 cm till the end of the growing season.

Rows were spaced 75.0 cm apart and 18.0 cm between holes giving about 70.000 holes ha^{-1}. After establishment, stands were hand-thinned to two plants per hole, which account for 140,000 plants ha^{-1}. Treatments consisted of five nitrogen rates for the drip irrigation (0, 60, 120, 180, and 240 kg N ha^{-1}) and only one nitrogen rate 180 kg N ha^{-1} for the surface irrigation, which is the recommended rate by MAAR. Nitrogen fertilizer as urea 46% was applied for the surface irrigated cotton in a three unequally split applications according to the MAAR recommendation: (*30% before planting, 50% at thinning and 20% before flowering*). A labelled ^{15}N subplot (1.0 m^2) in each experimental unit was established for the surface irrigated plots. The nitrogen fertilizer was injected through the drip system every third irrigation, whenever possible, in an equally split eight applications

[1] Bp: Before planting.
[2] Ah: After harvest.

for the drip irrigated cotton. Labelled 1.0 m^2 subplots were established in the central row of each experimental unit, for all nitrogen treatments of the fertigated cotton and fertilized with ^{15}N labelled urea through a secondary micro-drip system, allocated next to each experimental unit. Phosphorus fertilizer was added according to the soil phosphorus availability index in 1995, 1996, 1997 and 1998, (80, 19, 19, 56 kg P_2O_5 $ha^{-1)}$, respectively. No addition of K was made based on soil testing information. All other cultural practices were conducted similar to the common practices in the area.

Each experimental unit for both surface and fertigation practices was 75.0 m^2 which provided five rows each 20.0 m long and 3.75 m width. Each lateral drip line had 50 emitters (40.0 cm between emitters), and the emitter discharge was 4 L h^{-1}. An example of irrigation and fertilizer scheduling is shown in Table II. Volumes of water applied by irrigation for surface and drip irrigated cotton were monitored by two in -line propeller-type flow meters. Two neutron probe access tubes were installed in each experimental unit in order to monitor the soil moisture content and to provide feedback data for irrigation scheduling. Irrigation amounts were applied uniformly to all nitrogen treatments of drip irrigated cotton. The surface irrigated cotton was irrigated uniformly at 80% of F.C. using the neutron probe feedback data. The final irrigation (crop termination) was applied according to soil moisture level and to provide adequate soil moisture for the full development of almost all-mature bolls. All fertilizer nitrogen for drip irrigated cotton was supplied as solution of urea 46% and injected directly into the irrigation water by proportional microtubes with the same flow rate corresponding to the nitrogen treatments, (spaghetti tubes), using proportional–type injectors (Dosatron proportional injector D8R).

Soil samples were taken to a depth of 100 cm in 25 cm increments prior to the initiation of the experiment in order to determine the chemical properties of the soil and also the phosphorus requirements of the cotton crop (Table I). Each soil sample was analyzed for pH, Ec, CEC, exchangeable cations, organic matter using standard procedures. The total N was determined by the Kjeldahl method [16] and phosphorus by the molibdo-ascorbic acid procedure as outlined by Olsen and Sommers [17]. Furthermore, soil samples were collected from all the experimental units at planting, peak flowering and after harvest and analyzed for NO_3^- and NH_4^+ in order have a clear idea about the nitrogen status during the course of the experiment and to take actions in case of emergency as well as to compare the residual nitrogen.

Whole above-ground plant samples were collected from the labelled subplots at physiological maturity in the 1995, 1996, 1997 and 1998 growing seasons. The above-ground portion of the cotton plants was harvested by cutting the main stem immediately below the cotyledonary node. Plant samples were separated immediately into stems, leaf petioles, leaf blades and fruiting forms (squares, flowers, and bolls). Bolls were separated into burs, seeds and lent. Therefore, the fruiting forms included squares, flowers, immature bolls, seeds and burs. No attempts were taken to account for shed leaves, flowers and bolls. Mature bolls were weighted and then partially delineated, seeds and burs dried and grounded. Further, they were mixed uniformly with the other components of the fruiting forms. All other plant parts, except lint (lint was exempted from nitrogen analysis, based on the finding of Bassett et al. [18], which showed that lint contains only trace levels of mineral nutrient) were dried at 65°C, for 48 h, weighted, ground and analyzed for total N, and ^{15}N a.e % by emission spectrometry (Jasco-^{15}N analyzer). Calculation of Ndff, Ndfs, N-fertilizer yield and NFUE was performed as outlined by Zapata [19]. Total dry matter weight was obtained by the summation of the individual parts. The experimental design was a randomized complete block design with six replicates (Figure 1).

The seed cotton yield of all treatments was determined from the yield subplots of the corresponding treatments at maturity by two-hand pickings. The first picking was started on 16/9/1995–22/9/1996–16/9/1997 and 17/9/1998. Lint properties were determined on 20–bolls randomly hand picked samples from all experimental units. The second picking was almost 15 days after the first one.

TABLE II. IRRIGATION SCHEDULING AND FERTILIZER APPLICATION, 1995

Date	Fertilizer Application	Drip Irrigation	Amount of water applied $m^3\ ha^{-1}$	Fertilizer Application	Surface Irrigation	Amount of water applied $m^3\ ha^{-1}$
10/4/95		✓	195	✓	✓	981
17/4/95					✓	490
27/4/95	✓	✓	142			
7/5/95		✓	142			
9/5/95					✓	514
16/5/95	✓	✓	142			
18/5/95					✓	515
23/5/95		✓	144			
27/5/95		✓	145	✓	✓	499
3/6/95	✓	✓	143			
5/6/95					✓	485
10/6/95		✓	141			
13/6/95					✓	603
16/6/95		✓	147			
21/6/95	✓	✓	140		✓	493
27/6/95		✓	144	✓	✓	485
3/7/95		✓	510			
4/7/95					✓	870
8/7/95	✓	✓	496			
10/7/95					✓	867
14/7/95		✓	487			
17/7/95					✓	874
20/7/95		✓	493			
23/7/95					✓	853
26/7/95	✓	✓	495			
31/7/95					✓	856
1/8/95		✓	498			
8/8/95		✓	495		✓	880
13/8/95	✓	✓	495			
14/8/95					✓	864
19/8/95		✓	505			
20/8/95					✓	878
24/8/95	✓	✓	489			
26/8/95					✓	878
29/8/95		✓	498			
31/8/95					✓	877
5/9/95		✓	492			
7/9/95					✓	869
Total	**8**	**23**	**7578**	**3**	**20**	**14630**

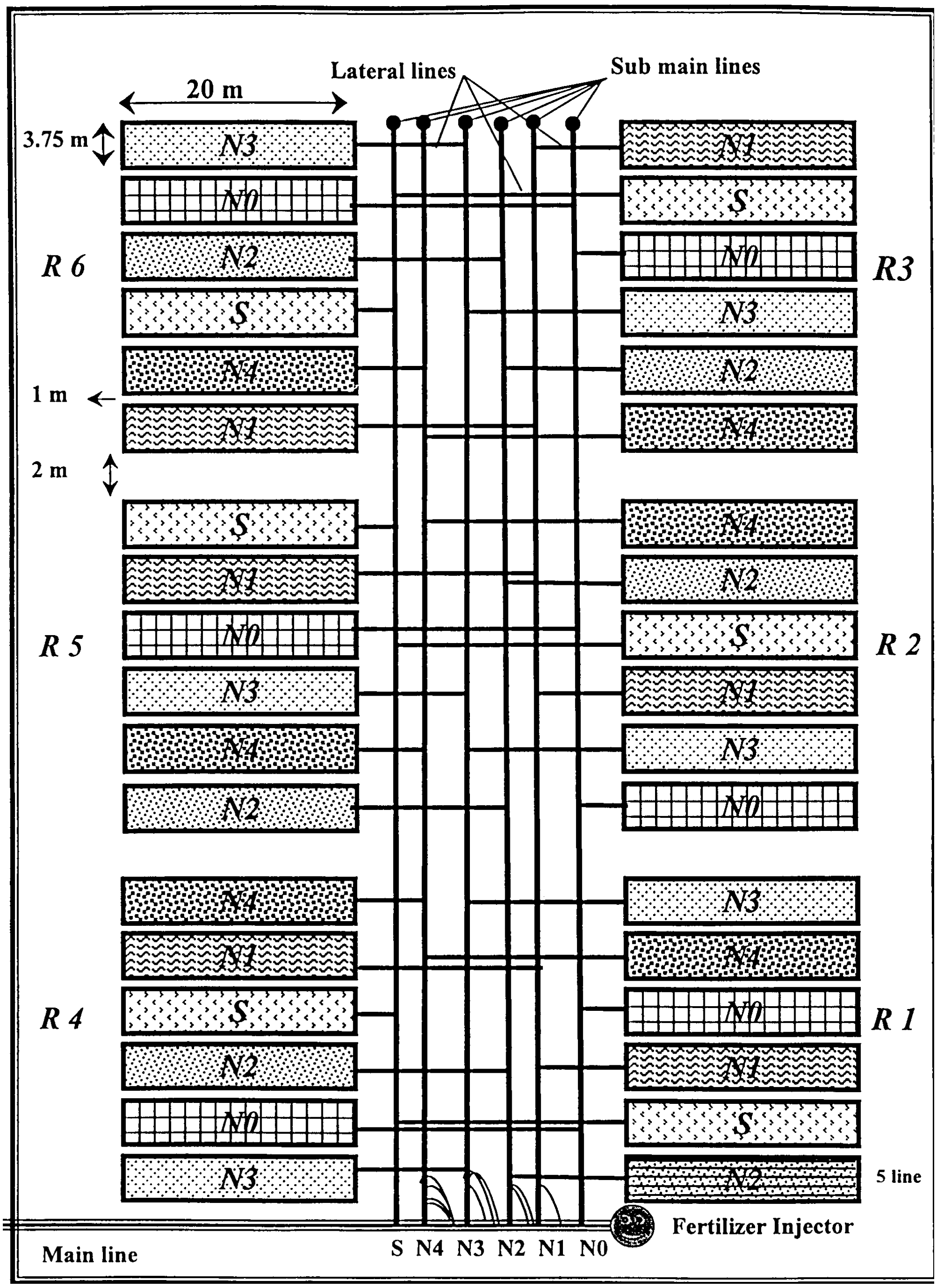

Figure 1. Experimental layout. Hama, 1995–1998.

Total dry matter production, seed cotton yield, lint properties and earlyness were subjected to analysis of variance (ANOVA) and mean separation using Duncan's Multiple range test (DMRT) at 5% level of confidence, using the costat statistical analysis procedure.

In the 1998 growing season a set of tensionics was installed for one replicate in order to closely monitor the downward movement of the NO_3^{-}

All nitrogen treatments under drip irrigation received a total amount of 7,578, 4,642, 5,111 and 5,445 m^3 ha^{-1} of irrigation water for 1995, 1996, 1997 and 1998, respectively; otherwise, under the conventional surface irrigation the amount of irrigation water applied was 14,630, 14,739, 10,124 and 10,944 m^3 ha^{-1} for 1995, 1996, 1997 and 1998, respectively, (Figure 2).

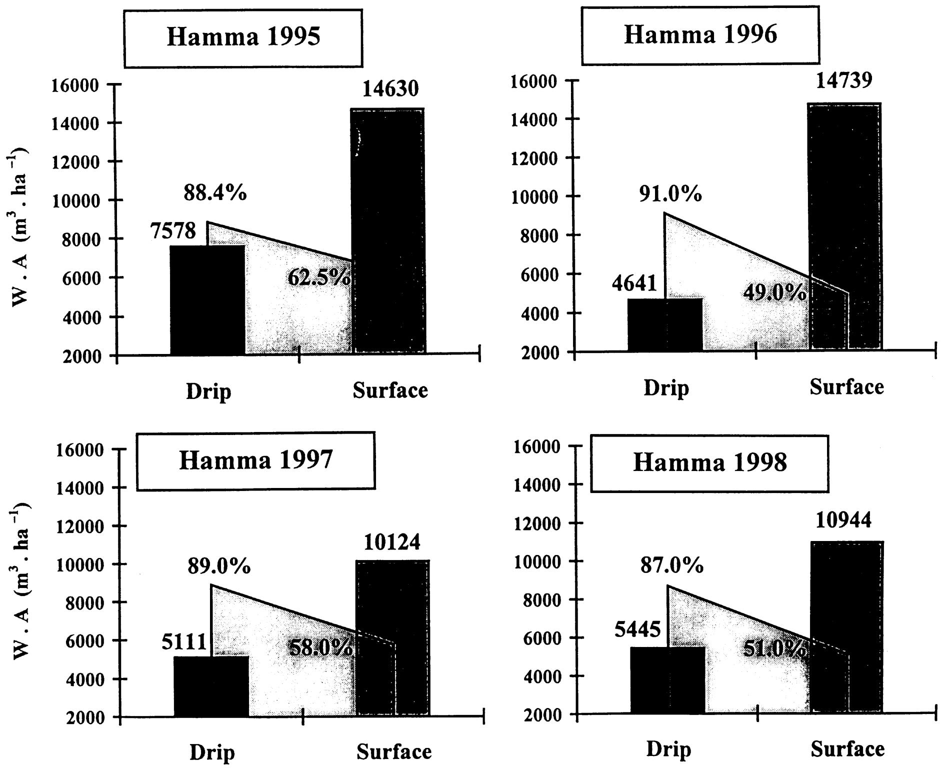

Figure 2. Effect of irrigation methods on water application 95-98.

3. RESULTS AND DISCUSSION

The intention of this experiment was to compare FUE, WUE, dry matter yield, seed cotton yield and lint properties as influenced by nitrogen fertilizer rates and method of irrigation.

3.1. Dry matter, N uptake and NFUE

Dry matter production, N-uptake and NFUE at physiological maturity for the 1995 growing season are summarized in Table III. The yield of dry matter was increased with the application of nitrogen fertilizer up to 240 kg N ha^{-1}. The highest total dry matter yield was observed for the highest nitrogen treatment of the drip irrigated cotton,(N_4), and the lowest for the unfertilized cotton treatment (N_0). Furthermore, the (N_3) treatment produced a higher DM yield than the comparative surface irrigated treatment, which received the same amount of N fertilizer but applied in a different way. The nitrogen uptake followed almost the same trend as the DM yield except the fact that the N uptake of the surface irrigation treatment was higher than the lowest N-rate of the drip irrigated cotton (N_1). The average N uptake data for cotton under irrigation methods and the N rates for all growing seasons are summarized in Tables III, IV, V, VI. The total N uptake at physiological maturity and throughout the growing seasons showed a wide variation among N rates and irrigation methods. Differences between growing seasons from the standpoint of N uptake must be related to seasonal variations, environmental conditions as well as the availability of available forms of nitrogen in the root zone in relation to the available supply and active root system. Furthermore, the tables show a pronounced interaction between irrigation methods and N rates. The amount of nitrogen taken up by the comparative N_3 treatment vs S treatment followed the same trend and varied widely due to the same reasons as well as N recovery. The total amount of N taken up by N_3 varied from 280 kg N ha^{-1} in 1995 to 460.0 kg N ha^{-1} in 1997, whereas, the N uptake of the (S) treatment varied from 167.0 kg N ha^{-1} in 1996 to 352.0 kg N ha^{-1} in 1997. The nitrogen fertilizer use efficiency (NFUE) was highest for the N_3 and N_4 treatments and lowest for the surface irrigation treatment (S).

TABLE III. EFFECT OF N RATES AND IRRIGATION METHODS ON DM, N UPTAKE AND NFUE AT PHYSIOLOGICAL MATURITY, 1995

Tmts	DM	Total N	N-uptake	Ndff	N-fert yield	NFUE
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
N_0	10828	0.96	103.5			
N_1	16517	0.91	149.5	9.0	13.4	22.3
N_2	17936	1.10	190.2	16.1	30.7	25.6
N_3	20885	1.34	279.7	19.9	55.6	30.9
N_4	25939	1.23	318.4	22.5	71.7	29.9
S	15817	1.24	195.6	18.9	36.9	20.5

TABLE IV. EFFECT OF N RATES AND IRRIGATION METHODS ON DM, N UPTAKE AND NFUE AT PHYSIOLOGICAL MATURITY, 1996

Tmts	DM	Total N	N-uptake	Ndff	N-fert yield	NFUE
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
N_0	7163.0	1.52	109			
N_1	14486.0	1.73	251	6.6	16.5	27.5
N_2	12062.0	1.88	227	18.0	40.8	34.0
N_3	19357.0	1.79	347	15.0	52.1	29.0
N_4	19045.0	2.10	395	18.1	71.3	29.7
S	8901.0	1.90	167	31.6	52.7	29.3

TABLE V. EFFECT OF N RATES AND IRRIGATION METHODS ON DM, N UPTAKE AND NFUE AT PHYSIOLOGICAL MATURITY, 1997

Tmts	DM	Total N	N-uptake	Ndff	N-fert yield	NFUE
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
N_0	9405	1.7	161.0			
N_1	19135	2.0	377.6	14.0	52.8	88.0
N_2	19832	2.2	436.6	18.2	79.5	66.3
N_3	18714	2.5	459.7	36.0	164.9	91.6
N_4	19848	2.6	514.5	42.2	217.1	90.5
S	16281	2.2	352.0	41.0	145.6	80.1

TABLE VI. EFFECT OF N RATES AND IRRIGATION METHODS ON DM, N UPTAKE AND NFUE AT PHYSIOLOGICAL MATURITY, 1998

Tmts	DM	Total N	N-uptake	Ndff	N-fert yield	NFUE
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}	%
N_0	10671	1.9	207.0			
N_1	15944	2.2	348.0	12.0	40.2	67.0
N_2	19748	2.4	481.0	22.0	105.0	88.0
N_3	18704	2.4	446.0	28.0	126.0	70.0
N_4	17845	2.5	440.8	30.0	130.1	54.0
S	13954	2.3	326.0	24.0	77.2	43.0

Still the NFUE of the fertigated treatments is considered very low, especially in the 1995 and 1996 growing seasons, and not up to the standard noted in the literature. This could be attributed to either lateral movement of ^{14}N urea from adjacent drip lines, or from the emitters next to the micro drip system installed to deliver ^{15}N urea to the labelled subplots, or cotton plants of the labelled subplots may have introduced roots into the soil with an unlabelled neighbouring drip line or vice versa. As mentioned earlier, the distance between lines is 75.0 cm, the midway between two drip lines is 37.5 cm. This distance seems not enough to prevent lateral movement of NO_3^- ions in the soil solution. According to Mc Gee et al. [20], using ^{15}N methodology, they found that 21% of the total N applied was taken up by plants 45.0 cm outside of the subplots. Coal and Sanchez [21] reported that ^{15}N was recovered by sugarcane (*Saccharum officinarum* L.) growing less than 75.0 cm from the soil applied ^{15}N band.

Follett et al. [22] found an ^{15}N recovery by wheat (*Triticum aestivum* L.) plants of less than 45.0 cm from the labelled subplot. These results suggest that lateral movement of NO_3^- and probably NO_2^- may occur. Another possible explanation could be due to the last application of N fertilizer as well as the final irrigation. In our case, it seems that both phenomena took place and therefore, a dilution effect of the ^{15}N recovery in the plant tissue occurred and indirectly affected the NFUE. Moreover, the initial available nitrogen in the soil seems to be sufficient to support the plant growth, and actually this is to some extent true, because the average seed cotton yield in the Syrian Arab Republic is 3252 kg ha^{-1}. The unfertilized drip irrigated treatment actually produced 3791 kg ha^{-1} seed cotton which is higher than the average seed cotton yield in the Syrian Arab Republic. Although drip irrigation, and water management can be accounted for this relatively high yield, still it gives a good idea about the sufficiency of available nitrogen in the soil.

The total above-ground dry matter production, N-uptake and NFUE of cotton crop for the 1996 growing season are given in Table IV.

It seems that the irrigation method and nitrogen application had a marked effect on DM and N uptake. Dry matter yield was increased with nitrogen application relative to the control (No). The total amount of DM production for all fertigation treatments was 19045, 19357, 12062, 14486 and 7163 kg ha^{-1} for N_4, N_3, N_2, N_1 and N_0, respectively. Moreover, all fertigation treatments produced higher DM yields in comparison to the surface irrigation treatment, which produced 8901 kg ha^{-1}. Moreover, the N_3 treatment produced much higher DM than the corresponding (S) treatment, which received the same amount of N fertilizer.

The dry matter production of the 1996 growing season did not follow the same trend as in the 1995 growing season and the overall production was lower. Also the dry matter production of the N_2 treatment was lower than the N_1 treatment for unknown reasons which might be attributed to the delay in maturity for this particular treatment. The cause of the delay could not be verified but it was obvious, and it was reflected in the earlyness, and N-uptake parameters. With the exception of the (N_2) treatment, the N-uptake was increased with increasing nitrogen application rate for all fertigation treatments. The amounts of nitrogen taken up by the cotton crop at this growth stage were 109, 251, 227, 347, 395 and 167 kg N ha^{-1} for the N_0, N_1, N_2, N_3, N_4 and S treatments, respectively. The amount of N taken up by the N_3 treatment was much higher than that of the surface irrigated treatment. This large differences could be attributed to the higher DM yield of the N_3 treatment, irrigation method and timing of N application.

In the 1997 growing season, the dry matter yield was higher than that of 1996 but the differences between DM yields for the fertigated treatments were minimal. Still it followed the same trend as in 1995. The effect of nitrogen fertilization and irrigation methods on N uptake was obvious and was characterized by being relatively higher than the previous seasons, which might be due to the relatively higher initial soil nitrogen status this season as well as the timing of N fertilizer application and the final irrigation (Table V).

In the 1998 growing season the DM production, N uptake and NFUE (Table VI) followed almost the same trend as in the 1997 growing season with the obvious decrease in almost all parameters tested. Still the results obtained showed superiority of all fertigated treatments over the surface irrigated treatment. A characteristic feature of the last growing seasons (1997 and 1998) is the relatively higher N uptake by almost all treatments. The explanations for this phenomenon could be either the relatively high fertility status of the soil but the most important is the last injection of the nitrogen fertilizer. Since for the last two seasons, nitrogen injection was terminated about 40 days before harvesting which gave the crop the required time needed to take-up all the available nitrogen in the rhizosphere and have it assimilated in the plant tissues. This is clearly reflected in the NFUE which was improved 2–3 fold relatively to the first two growing seasons.

3.2 Seed cotton yield and lint properties

The effect of N fertilization and irrigation methods on seed cotton yield and earlyness for all growing seasons are given in Table VII.

TABLE VII. EFFECT OF N RATES AND IRRIGATION METHODS ON SEED COTTON YIELD (kg ha^{-1}) AND EARLINESS, 1995

Treatments	N_0	N_1	N_2	N_3	N_4	S	LSD
1st Picking	3228 d	4053 c	4358 b	4510 b	4712 a	3109 d	195.7
2nd Picking	652 e	757 d	1198 c	1326 a	1345 a	1253 b	36.9
Earliness %	85 a	84 a	79 b	78 b	78 b	72 c	1.2
Total yield	3791 f	4810 d	5556 c	5837 b	6058 a	4362 e	187.6
			1996				
1st Picking	2509 e	3278 d	3546 c	3873 b	4269 a	2505 e	228
2nd Picking	774 b	817 b	1228 a	1186 a	1292 a	786 b	137
Earliness %	77 ab	80 a	74 b	77 ab	77 ab	76 b	3.3
Total yield	3283 e	4095 d	4774 c	5056 b	5561 a	3291 e	175
			1997				
1st Picking	3444 b	3694 ab	3993 a	3991 a	3943 a	3082 c	307
2nd Picking	615 b	746 b	1730 a	1182 a	1280 a	1151 a	235
Earliness %	85 a	83 a	75 b	77 b	76 b	73 b	6
Total yield	4059 c	4439 b	5364 a	5173 a	5223 a	4233 c	200
			1998				
1st Picking	3572 d	4122 c	4529 ab	4231 bc	4740 a	3599 d	370
2nd Picking	255 d	437 b	627 a	637 a	649 a	359 c	68
Earliness %	93 a	91 b	88 c	87 c	88 c	91 b	1.6
Total yield	3827 d	4559 c	5157 ab	4869 bc	5389 a	3958 d	370

Means followed by the same letter within a row are not statistically different at 5% level of confidence according to DMR test.

Increasing nitrogen rate significantly increased the seed cotton yield, and the most pronounced response was in most cases due to the higher nitrogen rate for the drip irrigation or in another words the positive interaction between irrigation method and N rate. The yield of seed cotton was significantly increased by the nitrogen fertilizer input and irrigation method for the 1995, 1996, 1997 and 1998 growing seasons. Analysis of variance from the standpoint of irrigation methods revealed that drip irrigation showed superiority over the surface conventional irrigation under all nitrogen levels. Seed cotton yield was significantly increased by 27, 47, 54 and 60% for N_1, N_2, N_3 and N_4 respectively, in comparison to the control (N_0) in 1995, while in 1996 the yield of the seed cotton followed the same trend and increased by 25, 45, 54 and 69% for N_1, N_2, N_3 and N_4, respectively. In the 1997 growing season the yield increases followed the same trend, yet the magnitude of the increases was smaller due to the relatively high yield of the control (N_0). The seed cotton yield was increased by 9, 32, 27 and 29% for the N_1, N_2, N_3 and N_4 treatments respectively. In the 1998 growing season the seed cotton yield increase was 19, 35, 27, and 41% for the N_1, N_2, N_3 and N_4 treatments, respectively. Furthermore, when drip irrigated treatments were compared with the surface irrigated treatment, almost the same trends were observed. In 1995, the seed cotton yield was increased by 10, 27, 34 and 39% for the N_1, N_2, N_3 and N_4, respectively. While in 1996, the increases in seed cotton yield were 24, 45, 54 and 69% for N_1, N_2, N_3 and N_4, respectively. The same trend was observed for 1997 but to a lesser extent, seed cotton yield was increased by 5, 27, 22 and 23% for the N_1, N_2, N_3 and N_4 treatments, respectively. In 1998, the increases in seed cotton yield were 15, 30, 23, and 36% for the N_1, N_2, N_3 and N_4, respectively.

The results suggest that timing of nitrogen application and irrigation method had a pronounced effect on cotton yield.

Earliness which is characterized by the amount of seed cotton yield of the first picking over the total amount of seed cotton yield for the 1995, 1996 , 1997 and 1998 growing seasons is summarized in Table VII. In the 1995 growing season, the unfertilized drip irrigation treatment (N_0) and the lowest nitrogen rate of the drip irrigation significantly reached almost 85% of maturity which was earlier than the other treatments while there was no significant difference in earliness between the N_2, N_3 and N_4 treatments. The surface irrigated cotton treatment was significantly delayed in maturity relatively to all other drip irrigation treatments. In the 1996 growing season, there was no significant difference between all treatments including the surface irrigation treatment with regard to earliness, with exception of the N_1 treatment, which showed superiority over the N_2 and S treatments. The change in the course of earliness might be caused by better irrigation and water management this season where the effective root depth was 30.0 cm from planting till peak bloom and 60.0 cm till maturity and this considerably lowered the water requirement of the cotton crop under all nitrogen treatments and irrigation methods. In the 1997 growing season, the N_0 and N_1 treatments reached maturity significantly earlier than the other treatments (N_2, N_3, N_4 and S). The surface irrigation treatment was delayed in maturity in comparison to those fertigated treatments. Almost the same trend was observed for the 1998 growing season.

The influence of nitrogen rate and irrigation method on lint properties for the 1995, 1996, 1997 and 1998 growing season are presented in TABLE VIII. It seems that both factors, irrigation methods and nitrogen fertilizer rates, had little impact on % gin turnout, fiber length, uniformity ratio, pressly index, stelometer, elongation, fineness, and maturity. In some cases the fertigation treatments showed superiority over the (S) treatment with regard to these parameters, and no major changes were observed due to the tested treatments.

3.3. Water use efficiency

Because of its simplicity, field water use efficiency (E_f) is adapted in this study. It is defined as unit yield produced per unit of actual amount of irrigation water applied. This parameter, actually reflects the characteristics of the irrigation method employed in this study. It is a very important indicator of the relative performance of different irrigation methods under different nitrogen fertilizer levels within the specified irrigation method, as in our case study. Furthermore, in this study E_f was calculated for the seed cotton yield (E_{fY}) and dry matter yield (above-ground biomass–seed cotton yield) (E_{fd}). Dry matter production is an important parameter which reflects the performance of the cotton crop and it is a key factor for farmers as feed stuff. At the harvesting time cotton residue is the only available fodder for the animals and this is considered by the farmers as an additional source of income. Table IX shows the values of the field water use efficiency for all treatments tested during the course of this study. It is evident that the highest E_{fd} of 4.06 [kg (ha m^3) $^{-1}$] was produced for the fertigated cotton treatment of N_3 in 1996, in comparison with the corresponding surface irrigated treatment. Furthermore, all cotton treatments irrigated by drip irrigation showed a much higher E_{fd} than the surface irrigated treatment which in term received the highest amount of irrigation water for all growing seasons indicating wasteful water application by the conventional irrigation and at the same time a better performance of the drip irrigation method as well as a higher productivity. Also the injection of nitrogen fertilizer through the drip system improved much the E_{fd}, which again reflected the effect of fertilizer input as a function of the irrigation method on field water use efficiency. It might be concluded that a better E_{fd} could be attained by good irrigation and fertilization management. Field water use efficiency of the seed cotton yield (E_{fy}) parameter is also considered in this study and the results are shown in Table IX.

TABLE VIII. EFFECT OF N RATES AND IRRIGATION METHODS ON COTTON LINT PROPERTIES, 1995

Treatments	N0	N1	N2	N3	N4	S	LSD
Gin turnout %	41.2 ab	42.2 a	39.6 b	39.3 b	39.6 b	39.3 b	2.2
Length	1138 a	1144 a	1170 a	1165 a	1129 a	1133 a	43
Uniformity %	56.4 a	56.3 a	55.0 a	56.8 a	56.9 a	56.0 a	2.75
Pressly	9.1 a	9.2 a	9.4 a	9.0 a	9.4 a	9.1 a	0.61
Stelometer	24.6 ab	24.6 ab	25.6 ab	24.9 ab	26.3 a	24.1 b	1.57
Elongation	5.0 a	5.2 a	4.9 a	5.1 a	4.7 a	4.9 a	0.61
Fineness	4.3 a	4.4 a	4.3 a	4.5 a	4.6 a	4.3 a	0.33
Maturity %	71.0 a	72.9 a	70.3 a	73.4 a	73.9 a	72.8 a	4.5
1996							
Gin turnout %	41.8 a	40.6 a	41.0 a	40.6 a	40.5 a	40.5 a	1.6
Length	1197 a	1152 b	1159 b	1156 b	1145 b	1145 b	25.1
Uniformity %	59.0 a	58.8 a	58.9 a	59.8 a	60.1 a	59.3 a	1.44
Pressly	9.7 a	10.0 a	9.8 a	9.9 a	9.8 a	10.0 a	0.31
Stelometer	25.9 abc	25.3 bc	24.8 c	27.7 abc	26.6 a	26.0 ab	1.06
Elongation	5.4 a	5.0 b	5.0 b	5.1 b	5.1 b	5.0 b	0.20
Fineness	4.3 b	4.3 b	4.5 ab	4.6 ab	4.8 a	4.8 a	0.32
Maturity %	78.3 b	81.8 a	81.0 a	81.5 a	81.4 a	83.2 a	2.3
1997							
Gin turnout %	41.4 a	41.1 a	41.0 a	40.5 a	41.6 a	40.8 a	1.6
Length	1187 a	1183 a	1184 a	1191 a	1161 a	1155 a	32.5
Uniformity %	54.4 a	59.3 a	58.4 a	59.4 a	58.3 a	58.7 a	4.8
Pressly	10.0 a	10.0 a	9.8 a	10.0 a	9.3 a	9.8 a	0.68
Stelometer	26.0 c	26.1 bc	26.5 abc	27.7 ab	26.3 bc	28.0 a	1.5
Elongation	5.5 a	5.6 a	6.1 a	6.0 a	5.4 a	5.8 a	0.83
Fineness	4.7 a	4.6 a	4.8 a	4.7 a	4.8 a	4.8 a	0.17
Maturity %	92.0 a	88.0 a	91.0 a	89.0 a	89.0 a	93.0 a	7.4
1998							
Gin turnout %	37.6 a	40.2 a	39.0 a	38.4 a	37.7 a	38.3 a	2.4
Length	1166 ab	1164 ab	1176 a	1147 ab	1160 ab	1117 b	47.0
Uniformity %	57.0 a	56.0 a	57.9 a	58.0 a	57.1 a	56.8 a	2.0
Pressly	10.4 a	10.0 a	10.4 a	10.2 a	10.5 a	10.1 a	0.90
Stelometer	26.7 a	27.3 a	29.2 a	27.2 a	27.5 a	28.5 a	2.80
Elongation	4.6 a	5.1 ab	5.0 ab	5.2 b	5.0 ab	4.9 ab	0.50
Fineness	4.1 a	4.6 a	4.7 a	4.7 a	4.7 a	4.7 a	0.31
Maturity %	86.0 a	88.0 a	87.0 a	86.0 a	83.0 a	86.0 a	8.10

Means followed by the same letter within a row are not statistically different at 5% level of confidence according to DMR test.

TABLE IX. DRY MATTER PRODUCTION, SEED COTTON YIELD, AND WATER USE EFFICIENCIES E_{fd}, E_{fy}

Treatments			E_{fd} [kg (ha m^3)$^{-1}$]					
	1995	DM kg ha^{-1}	1996		1997		1998	
N0	1.43	10828	1.50	7163	1.84	9405	1.96	10671
N_1	2.18	16517	3.04	14486	3.74	19135	2.93	15944
N_2	2.37	17936	2.53	12062	3.90	19832	3.63	19748
N_3	2.76	20885	4.06	19357	3.70	18714	3.44	18704
N_4	3.42	25939	4.00	19045	3.90	19848	3.28	17845
S	1.08	15817	0.60	8901	1.61	16281	1.28	13954
		Seed cotton kg ha^{-1}			E_{fy} [kg (ha m^3)$^{-1}$]			
N0	0.50	3791	0.69	3283	0.79	4059	0.70	3827
N_1	0.64	4810	0.86	4095	0.87	4439	0.84	4559
N_2	0.73	5556	1.00	4774	1.05	5364	0.95	5157
N_3	0.77	5837	1.06	5056	1.01	5173	0.90	4869
N_4	0.80	6058	1.17	5561	1.02	5223	0.99	5389
S	0.30	4362	0.22	3291	0.42	4233	0.36	3958

It is obvious that fertigation practices improved the E_{fy} in he same way as it was proved for the dry matter production of the cotton crop. The highest E_{fy} was observed for the N_4 treatment [1.17 kg (ha m^3)$^{-1}$] in the 1996 growing season, while the lowest was [0.22 kg (ha m^3)$^{-1}$] for the surface irrigated treatment (S) for the same growing season. Furthermore, increasing the nitrogen input with the drip irrigation method improved the E_{fy}, and the overall E_{fy} was higher for all nitrogen treatments under drip irrigation in comparison to surface irrigation. The higher E_{fd} and E_{fy} values obtained with drip irrigation could be attributed to the adaptation of the fertigation practices which in term reflect the better irrigation scheduling, management, adequacy and improvement of nitrogen input and efficiency.

3.4. Nitrate movement

Nitrate movement was also monitored under this investigation for the last growing season using a set of tensionics. The measurements were taken just before every irrigation . The results obtained are still preliminary and represent only one growing season. Figure 3 shows some of the data obtained. The following could be the trend of this investigation:

1. There is deeper and faster movement of the NO_3^- under the surface irrigation in comparison to the fertigation practice.
2. The nitrate recovery is obvious under fertigation practices because it is mostly in the root zone, while most nitrate under surface irrigation seems to leach out behind the root zone and is considered unrecoverable.

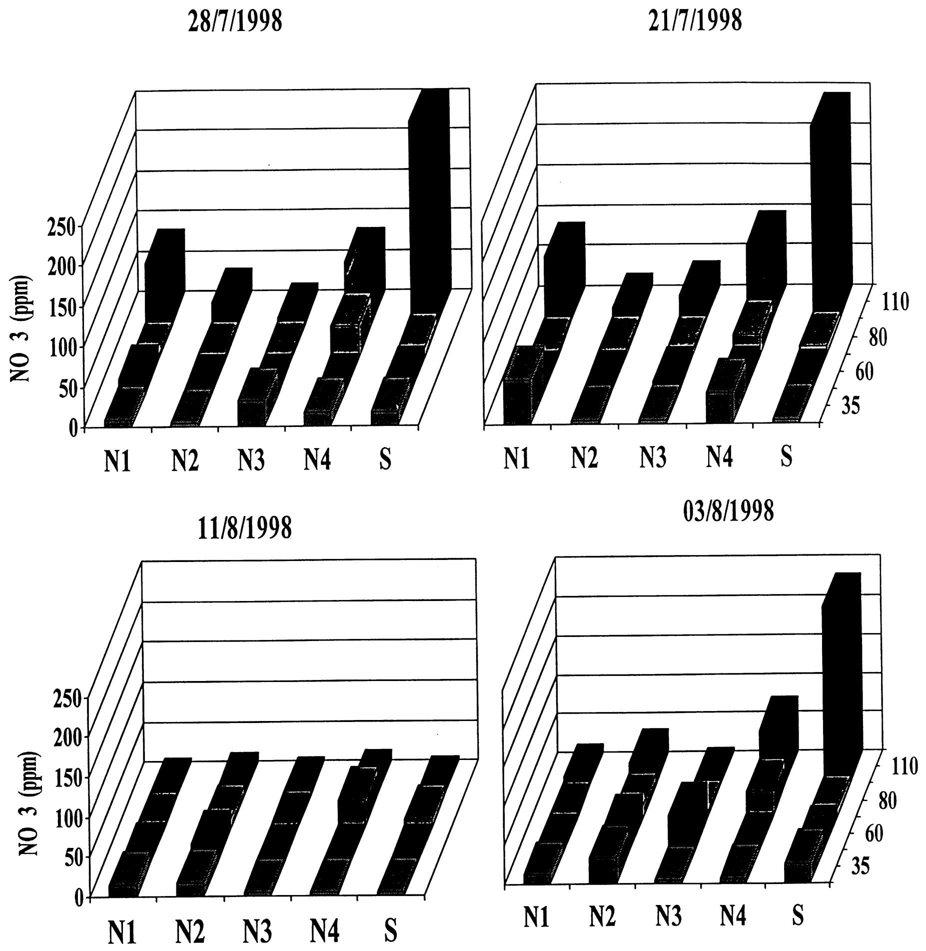

Figure 3. Effect of irrigation method on soil solution nitrate. 1998.
Drip: 09/5/98–03/6/98–27/6/98 –09/7/98–21/7/98–29/7/98–04/8/98
Surface: 09/5/98–16/6/98–09/7/98

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YIELD, NITROGEN UPTAKE AND NITROGEN USE EFFICIENCY BY TOMATO, PEPPER, CUCUMBER, MELON AND EGGPLANT AS AFFECTED BY NITROGEN RATES APPLIED WITH DRIP-IRRIGATION UNDER GREENHOUSE CONDITIONS

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Abstract

A number of experiments were conducted to investigate the influence of different N rates applied through drip irrigation on the growth and N uptake by tomato, pepper, cucumber, melon and eggplant under greenhouse conditions. It was found that, for tomato, the % NUE was significantly increased by applying the N fertilizer through fertigation (53.9 %) as compared to the soil application (34.0 %) at 100 mg N/L. In general, any further increase of N fertilizer did not have an improving effect on the tomato yield. With pepper, the % NUE was significantly increased by applying the N fertilizer in the irrigation water (49.2%) as compared to the soil application (33.9 %) at the same N level (140 mg N/L), being the optimum N rate under our greenhouse conditions. At a fertilization level of 100 mg N/L with fertigation, the % NUE was significantly increased as compared to the soil application. With respectively cucumber, melon and eggplant; the % NUE with fertigation was 63.4, 21.4 and 50.8 %, while with soil application it was 34,0 11.0 and 18.8 %.

1. INTRODUCTION

The maintenance of nutrients and water at optimum levels within the rhizosphere of plants is a primary factor for achieving higher yields, and increased fertilizer and water use efficiencies. Therefore, the application of water soluble fertilizers through the irrigation stream — fertigation — mainly with drip irrigation became a common practice in modern irrigated agriculture especially under greenhouse conditions [1,2,3,4,5].

Fertigation is widely practised for greenhouse vegetable production especially in the Antalya region of Turkey. However, further research is needed for a better understanding of this approach. Therefore, the objective of this study was to determine the effects of N fertilizer rates on yield, N uptake and nitrogen use efficiency of tomato, pepper, cucumber, melon and eggplant produced under greenhouse conditions using ^{15}N labelled fertilizer and drip irrigation techniques.

2. MATERIAL AND METHODS

Eight experiments (3 with tomato, 2 with pepper, 1 with cucumber, melon and eggplant) were conducted on a Mediterranean Terrarosa soil (53% sand, 13% silt and 34% clay) in the greenhouse of the Antalya Horticultural Research Institute, at different times. The soil used in the experiments had a pH of 7.5 and contained 1.08% organic matter, 10 ppm of $NaHCO_3$-extractable phosphorus and 396 ppm of exchangeable potassium. The irrigation water used in the experiments had an EC value of 0.73 dS/m and contained (in meq/L): Ca=5.86, Mg=0.26, Na=0.37, HCO_3=0.58, SO_4=5.87 and Cl=0.85.

The experiment consisted of four randomized blocks; each divided into five plots (for tomato, pepper and cucumber) or six plots (for melon and eggplant). Each plot was 3.6 m wide and 3.63 m long and contained four plant rows of which the two center rows were used for the harvest. Informative data about the experiments conducted are given in Table I.

The N application was done by drip irrigation. The drippers (one per plant) were spaced at 33 cm. The fertilizer N (ammonium sulphate) rate used was respectively 0, 50, 100, 150 mg N/L for spring and whole season tomato, spring 1996 cucumber, melon and eggplant, 0, 67, 134 and 201 mg N/L for spring 1994 tomato and pepper, and 0, 70, 140, 210 mg N/L for whole season pepper. In addition, soil applications of ammonium sulphate at a rate of 300 kg N/ha (1/3 before planting + 2/3 during the growth stages) and a slow release N fertilizer (of which, 300 kg N/ha was applied to the plots before planting) were carried out as treatments for tomato, pepper and cucumber and were applied in 3 equal portions at planting, initiation of flowering and fruit setting. They were also drip irrigated. Furthermore, for melon and eggplant slow release urea (400 kg N/ha) was also included as a treatment and it was mixed with the soil before planting. Phosphorus as H_3PO_4 and K as K_2SO_4 were applied through the irrigation system at rates of 60 and 180 mg/L, respectively.

^{15}N isotope sub-plots were established in each plot of each experiment. Therefore, the drippers of the three adjacent plants in the second row of each plot were blocked and respectively, 3.3% ^{15}N a.e. in the 1994 experiments and 2.0% ^{15}N a.e. in the 1995, 1996 and 1997 experiments were applied by using inverted bottles.

The amount of water to be applied for each experiment was calculated according to Class A Pan using the procedures described by [6].

Harvested plants were separated into stem + leaves and fruit for tomato, pepper, cucumber, into stem, leaf, fruit skin, fruit and seed for melon, leave, stem and fruit for the eggplant. They were dried at 70^0 C and ground. Total N determinations were done on these samples using the micro Kjeldahl method and the ^{15}N analyses were done using a Jasco-150 emission spectrometer according to [7].

3. RESULTS AND DISCUSSION

Dry matter (t/ha), total N uptake (kg N/ha), Ndff (%) and Ndff (kg N/ha) for the different parts of each crop as influenced by the applied N rates are given in the a, b, c and d section of every table, respectively. In the e section of each table the averaged total marketable yield (t/ha), NUE (%) and WUE (kg/ha-cm) as influenced by the applied N rates are given in addition to the averaged total yield, N uptake and Ndff data. They also include the results of the statistical analyses made.

3.1. Tomato

The results of the spring 1994, spring 1995 and whole season tomato experiments are given in Tables II, III and IV, respectively. The whole season grown tomato gave a higher total dry matter contents, higher % Ndff and % NUE values and lower WUE values as compared to spring tomato. The lowest marketable and dry matter yields and the lowest total N uptakes were obtained with the control treatments (0 mg N/L), while the highest values were obtained with 100 mg N/L).

The fertilizer N uptake and % NUE by the tomato plant were significantly increased when the N fertilizer was applied in the irrigation water (fertigation) as compared to the soil N application at the same level.

3.2. Pepper

The results of the spring 1994 and whole season pepper experiments are given in Tables V and VI, respectively. The whole season grown crop gave lower marketable yields and WUE values, but higher total dry matter, % Ndff, and % NUE values as compared to the spring grown crop. The lowest marketable yields, dry matter yields and total N uptakes were obtained from the control treatments (0 mg N/L). Total dry matter and total N uptake by pepper were not significantly influenced by the N rates. However, the fertilizer N uptake and % NUE were significantly increased with fertigation as compared to the soil application at the same level.

3.3. Cucumber

The results of the experiment conducted with cucumber are given in Table VII. The lowest marketable and dry matter yields for cucumber were obtained with the control treatment (0 mg N/L), while significantly higher yields were obtained at the optimum N rate, 140 mg N/L, applied to the soil rather than through fertigation. However, the soil application treatment gave significantly lower % Ndff, % NUE and % WUE values as compared to the other N treatments.

3.4. Melon

The results of the experiment conducted with melon are given in Table VII. The lowest marketable and total dry matter yields were obtained with the control treatment (0 mg N/L), while the highest yields were found with the 150 mg N/L fertigation treatment. Lower yields were obtained when the N fertilizer was applied to the soil rather than into the irrigation water (fertigation). The amount of N uptake increased as the N rate increased. The N uptake values obtained from the soil applications were found to be lower than the fertigation treatments. The highest total N uptake occurred at the highest N rate (150 mg N/L). Although the same amount of N fertilizer was applied with the soil application treatment, lower fertilizer N uptake values were obtained with the soil application treatment as compared to the N2 (100 mg N/L) fertigation treatment.

The fertilizer N uptake and % NUE were significantly increased with fertigation compared to the soil application of N and the application of slow release N fertilizer at the same level of fertilization. The % NUE changed according to the N rate and N application method. In general, as the N rate increased the % NUE values decreased as expected.

3.5. Eggplant

The results of the experiment conducted with eggplant are given in Table VII. The lowest marketable and dry matter yields were obtained with the control treatment (0 mg N/L), while the highest marketable yield was found with 150 mg N/L. The highest dry matter yield was obtained with 100 mg N/L when the slow release N fertilizer was applied.

The fertilizer N uptake and % NUE were significantly increased with fertigation as compared to the soil application treatment at the same level of fertilization.

4. CONCLUSIONS

From the three experiments, it can be concluded that, for tomato, the % NUE was significantly increased by applying the N fertilizer through fertigation (53.9 %) as compared to the soil application (34.0 %) at 100 mg N/L. In general, any further increase of N fertilizer did not have an improving effect on the tomato yield.

On average of the two experiments with pepper, the % NUE was significantly increased by applying the N fertilizer in the irrigation water — fertigation — (49.2 %) as compared to the soil application (33.9 %) at the same N level (140 mg N/L), being the optimum N rate under our greenhouse conditions.

At a fertilization level of 100 mg N/L, the % NUE was significantly increased as compared to the soil application. With respectively cucumber, melon and eggplant; the % NUE with fertigation was 63.4, 21.4 and 50.8 %, while with soil application it was 34,0 11.0 and 18.8 %. [xx] Total amounts of N applied were 200, 400 and 600 kg N/ha, for 50, 100 and 150 mgN/L treatments, respectively.

TABLE I. TIME TABLE AND CHARACTERISTICS OF THE CONDUCTED EXPERIMENTS

Plant type	Variety Used	Planting date	First fruit picking	Harvesting date	Water applied (mm)
Spring 1994 Tomato Lycopersicon esculentum Mill	Sander	25 Feb. 1994	12 May 1994	4 July 1994	392
Spring 1995 Tomato Lycopersicon esculemtum Mill	Sander	31 Jan. 1995	8 May 1995	3 July 1995	345
Whole season Tomato Lycopersicon	Fantastic F144	10 Oct. 1994	16 Feb. 1995	25 May 1995	l427
Spring Pepper Capsicum annuum	Dora	25 Feb. 1994	12 May 1994	4 July 1994	392
Whole season Pepper Capsicum annuum	Dora	10 Sep. 1994	2 Nov. 1994	20 April 1995	260
Whole season Cucumber Cucumia salivus	Yerli	15 Oct. 1995	13 Nov. 1995	25 April 1996	325
Melon Melopepon L.	Polidor F1	28 Feb. 1997		30 July 1997	200
Eggplant Solanum melongena	Faselis F1	3 Sep. 1997	1 Dec. 1997	15 June 1998	435

TABLE IIa. DRY MATTER YIELD OF SPRING 1994 TOMATO (t/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	67	134	201	134
Stem + Leaves	5.2	5.5	4.8	5.0	5.7
Fruit	4.0	6.1	6.5	5.7	6.1

TABLE IIb. TOTAL N UPTAKE BY TOMATO (kgN/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	67	134	201	134
Stem + Leaves	59.8	91.9	93.8	103.2	88.7
Fruit	74.9	134.5	139.4	114.2	121.4

TABLE IIc. % Ndff BY TOMATO

	Nitrogen rate (mg N/L)			Soil application
	67	134	201	134
Stem +Leaves	51.0	57.6	57.4	50.7
Fruit	58.3	56.3	62.0	32.2

TABLE IId. FERTILIZER N UPTAKE BY TOMATO (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	67	134	201	134
Stem + Leaves	46.9	54.2	59.6	45.4
Fruit	78.3	77.4	71.0	39.1

TABLE IIe. AVERAGED TOTAL MARKETABLE AND DRY MATTER YIELDS, TOTAL N, Ndff, %NUE, AND WUE OF SPRING TOMATO (1994)

Tomato	Nitrogen rate[xx] (mg N/L)				Soil appl.
	0	67	134	201	134
Marketable yield (t/ha)	75.5c[x]	97.8a	96.3a	87.0b	95.6ab
Total D.M. (t/ha)	9.2b	11.7a	11.3a	10.5ab	11.9a
Tot. N (kg N/ha)	135.9c	226.3a	233.2a	217.3ab	210.1b
% Ndff	-	54.7a	57.0a	59.7a	41.4b
Total Fert. Uptake (kg N/ha)	-	123.9a	132.9a	129.7a	87.0b
% NUE	-	62.0a	33.2b	21.6c	21.8c
WUE (kg/ha-cm)	235.1d	245.8dc	297.4a	276.3b	253.7c

[x] Values in rows followed by the same letter are not significantly different at the 0.05 probability level.
[xx] Total amounts of N applied were 200, 400 and 600 kg N/ha for 67, 134 and 201 mg N/L treatments, respectively.

TABLE IIIa. DRY MATTER YIELD OF SPRING 1995 TOMATO (t/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	50	100	150	100
Stem + Leaves	5.7	5.0	4.9	4.9	5.3
Fruit	3.5	5.0	6.5	6.0	6.0

TABLE IIIb. TOTAL N UPTAKE BY TOMATO (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	50	100	150	100
Stem + Leaves	55.9	83.3	89.8	97.6	93.7
Fruit	58.4	97.1	160.1	128.4	130.2

TABLE IIIc. % NDFF BY TOMATO

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Stem + Leaves	56.8	73.6	75.4	51.9
Fruit	62.0	81.8	87.7	61.3

TABLE IIId. FERTILIZER N UPTAKE BY TOMATO (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Stem + leaves	47.6	66.0	73.0	47.4
Fruit	59.5	130.6	112.3	74.8

TABLE IIIe. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, Ndff, %NUE AND WUE OF SPRING TOMATO (1995)

Tomato	Nitrogen rate[xx] (mg N/L)				Soil appl.
	0	50	100	150	100
Marketable yield (t/ha)	66.0c[x]	92.3b	112.3a	94.3b	97.1b
Total D.M. (t/ha)	9.2c	9.9b	11.4a	11.0a	11.3a
Tot. N (kg N/ha)	114.2c	180.3b	249.9a	226.0a	223.9a
% Ndff	-	59.4b	77.7a	81.5a	56.9b
Total Fert.Uptake(kg N/ha)	-	107.1c	194.2a	184.2a	127.4b
% NUE	-	53.6a	48.6a	30.7b	31.9b
WUE (kg/ha-cm)	274.9c	298.9c	337.1a	306.4b	307.1b

[x]Values in rows followed by the same letter are not significantly different at the 0.05 probability level.
[xx] Total amounts of N applied were 160, 320 and 480 kg N/ha, for 50, 100 and 150 mg N/L treatments, respectively.

TABLE IVa. DRY MATTER YIELD OF WHOLE SEASON TOMATO (t/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	50	100	150	100
Stem + Leaves	4.5	4.3	4.3	4.6	4.6
Fruit	4.5	5.3	6.4	6.6	5.5

TABLE IVb. TOTAL N UPTAKE BY TOMATO (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application.
	0	50	100	150	100
Stem + Leaves	77.9	100.8	113.6	125.4	101.3
Fruit	79.4	107.2	134.9	124.1	112.9

TABLE IVc. % Ndff BY TOMATO

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Stem + Leaves	67.8	73.8	82.0	63.2
Fruit	66.4	72.9	84.5	66.3

TABLE IVd. FERTILIZER N UPTAKE BY TOMATO (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Stem + Leaves	67.8	83.7	102.5	63.9
Fruit	71.3	98.2	105.1	74.6

TABLE IVe. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, Ndff, %NUE AND WUE OF WHOLE SEASON TOMATO (1995)

Tomato	Nitrogen rate[xx] (mg N/L)				Soil appl.
	0	50	100	150	100
Marketable Yield (t/ha)	108.1c[x]	123.2b	136.6a	135.2a	118.3b
Total D.M. (t /ha)	9.0d	9.6c	10.7ab	11.1a	10.1bc
Tot. N (kg N/ha)	157.3c	208.0b	248.4a	249.4a	214.2b
% Ndff	-	67.1b	73.3ab	83.3a	64.7b
Total Fert.Uptake (gN/ha)	-	139.4b	182.1a	207.3a	138.2b
% NUE	-	69.7a	45.5b	34.5c	34.6c
WUE (kg/ha-cm)	206.7c	225.3ab	250.5a	252.8a	233.5ab

[x] Values in rows followed by the same letter are not significantly different at the 0.05 probability level.
[xx] Total amounts of N applied were 200, 400 and 600 kg N/ha, for 50, 100 and 150 mg N/L treatments, respectively

TABLE Va. DRY MATTER YIELD OF SPRING PEPPER (t/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	67	134	201	134
Stem + Leaves	4.9	5.6	5.3	5.3	6.0
Fruit	1.4	2.3	2.4	2.6	2.3

TABLE Vb. TOTAL N UPTAKE BY PEPPER (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	67	134	201	134
Stem + Leaves	118.9	182.0	178.8	193.9	163.3
Fruit	46.1	73.0	79.5	84.2	67.5

TABLE Vc. %Ndff BY PEPPER

	Nitrogen rate (mg N/L)			Soil application
	67	134	201	134
Stem + Leaves	57.9	51.0	40.1	32.8
Fruit	46.6	64.2	40.1	45.4

TABLE Vd. FERTILIZER N UPTAKE BY PEPPER

	Nitrogen rate (mg N/L)			Soil application
	67	134	201	134
Stem + Leaves	104.6	92.0	77.9	52.6
Fruit	33.8	50.9	34.2	30.5

TABLE Ve. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, Ndff, %NUE and WUE OF SPRING PEPPER (1994)

Pepper	Nitrogen rate[xx] (mg N/L)				Soil appl.
	0	67	134	201	134
Marketable yield (t/ha)	30.4c[x]	43.7ab	45.1a	42.8b	43.2ab
Total D.M. (t /ha)	6.4b	7.9a	7.7a	7.8a	8.3a
Tot. N (kg N/ha)	165.0d	255.0b	258.3b	278.0a	230.7c
Total Fert. Uptake (kg N/ha)	-	133.4ab	148.8a	112.3b	90.2c
% NUE	-	66.7a	37.2b	18.7c	22.6c
WUE (kg/ha-cm)	296.1c	353.5ab	361.7a	342.4b	331.8ab

[x] Values in rows followed by the same letter are not significantly different at the 0.05 probability level.
[xx] Total amounts of N applied were 200, 400 and 600 kg N/ha, for 67, 134 and 201 mg N/L treatments.

TABLE VIa. DRY MATTER YIELD OF WHOLE SEASON PEPPER (t/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	70	140	210	140
Stem + Leaves	5.8	6.1	5.8	6.0	6.2
Fruit	1.6	2.3	2.8	2.6	2.3

TABLE VIb. TOTAL N UPTAKE BY PEPPER (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	70	140	210	140
Stem + Leaves	132.4	202.3	215.8	239.3	198.1
Fruit	38.4	65.1	82.2	88.2	64.2

TABLE Vic. %Ndff BY PEPPER

	Nitrogen rate (mg N/L)			Soil application
	70	140	210	140
Stem + Leaves	63.1	82.4	81.9	62.2
Fruit	69.4	88.8	90.8	68.9

TABLE VId. FERTILIZER N UPTAKE BY PEPPER (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	70	140	210	140
Stem + Leaves	126.0	178.0	196.0	137.0
Fruit	44.7	67.7	80.9	44.1

TABLE Vie. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, Ndff, %NUE AND WUE OF WHOLE SEASON PEPPER (1995)

Pepper	Nitrogen rate[xx] (mg N/L)				Soil appl.
	0	70	140	210	140
Marketable yield (t/ha)	20.3d[x]	25.2c	31.3a	29.7ab	27.5b
Total D.M. (t / ha)	7.4b	8.4a	8.6a	8.6a	8.5a
Tot. N (kg N/ha)	170.9c	267.4b	297.9ab	327.6a	262.3b
% Ndff	-	66.2b	82.1a	86.3a	69.0b
Total Fert. Uptake (kg N/ha)	-	177.0d	244.6b	282.7a	181.0c
% NUE	-	88.5a	61.2b	47.1c	45.3c
WUE (kg/ha-cm)	273.8b	330.2a	338.4a	335.7a	327.8a

[x] Values in rows followed by the same letter are not significantly different at the 0.05 probability level.

[xx] Total amounts of N applied were 175, 350 and 525 kg N/ha, for 70, 140 and 210 mg N/L treatments, respectively.

TABLE VIIa. DRY MATTER YIELD OF CUCUMBER (t/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	70	140	210	140
Stem + Leaves	6.7	10.3	7.4	10.5	11.0
Fruit	2.6	4.4	3.0	4.5	4.8

TABLE VIIb. TOTAL N UPTAKE BY CUCUMBER (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application
	0	70	140	210	140
Stem + Leaves	112.2	196.7	160.6	233.1	144.1
Fruit	86.6	153.1	136.8	195.8	192.0

TABLE VIIc. %Ndff BY CUCUMBER

	Nitrogen rate (mg N/L)			Soil application
	70	140	210	140
Stem + Leaves	43.3	64.5	65.1	42.4
Fruit	42.1	63.4	62.2	28.9

TABLE VIId. FERTILIZER N UPTAKE BY CUCUMBER (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	70	140	210	140
Stem + Leaves	85.2	103.6	151.7	61.1
Fruit	64.5	86.7	121.8	55.5

TABLE VIIe. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, Ndff, %NUE AND WUE OF SPRING CUCUMBER (1995)

Cucumber	Nitrogen rate[xx] (mg N/L)				Soil appl.
	0	70	140	210	140
Marketable yield (t/ha)	86.6d[x]	146.6b	106.0c	150.5b	162.8a
Total D.M. (t/ha)	9.3b	14.7a	10.4b	15.0a	15.8a
Tot. N (kg N/ha)	197.8d	249.8c	297.4b	328.9a	286.1b
% Ndff	-	42.7b	64.0a	63.7a	35.6b
Total Fert. Uptake (kg N/ha)	-	106.7b	190.3a	209.5a	101.9b
% NUE	-	71.1a	63.4b	46.5c	34.0d
WUE (kg/ha-cm)	298.6c	354.2a	340.3ab	334.9b	310.5c

[x] Values in rows followed by the same letter are not significantly different at the 0.05 probability level.
[xx] Total amounts of N applied were 175, 350 and 525 kg N/ha, for 70, 140 and 210 mg N/L treatments, respectively.

TABLE VIIIa DRY MATTER YIELD OF MELON (t/ha)

	Nitrogen rate (mg N/L)				Soil application	Slow release
	0	50	100	150	100	100
Stem	0.5	0.9	1.0	0.8	0.8	0.8
Leaf	1.5	1.8	2.4	1.9	1.8	1.8
Fruit skin	0.5	0.5	0.7	0.6	0.5	0.5
Fruit	0.7	0.9	1.0	1.0	0.9	1.0
Seed	0.4	0.5	0.4	0.5	0.3	0.4

TABLE VIIIb TOTAL N UPTAKE BY MELON (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application	Slow release
	0	50	100	150	100	100
Stem	4.8	9.7	11.4	10.2	7.8	7.0
Leaf	23.6	30.5	41.4	39.9	33.8	32.0
Fruit skin	7.6	8.6	10.9	11.1	8.3	9.6
Fruit	11.6	18.3	20.1	26.9	15.9	19.6
Seed	13.3	12.6	11.0	13.5	6.0	10.3

TABLE VIIIc. %Ndff BY MELON

	Nitrogen rate (kg N/L)			Soil application
	50	100	150	100
Stem	31.0	50.9	64.0	52.7
Leaf	31.2	40.0	86.0	40.7
Fruit skin	47.6	66.3	76.8	56.0
Fruit	35.5	42.5	67.5	44.9
Seed	38.6	43.3	68.8	54.1

TABLE VIIId. FERTILIZER N UPTAKE BY MELON (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Stem	3.0	5.8	6.5	4.1
Leaf	9.5	16.6	34.3	13.7
Fruit skin	4.1	7.2	8.5	4.6
Fruit	6.5	8.5	18.1	7.2
Seed	4.9	4.8	9.3	3.3

TABLE VIIIe. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, % Ndff, % NUE AND WUE OF MELON (1997)

Melon	Nitrogen rate[xx] (mg N/L)				Soil appl.	Slow rel.
	0	50	100	150	100	100
Marketable yield (t/ha)	28.4c[x]	35.3b	44.3a	42.1a	36.9b	37.4b
Total D.M. (t/ha)	3.6c	4.7b	5.4a	4.7b	4.3bc	4.5bc
Tot. N (kg N/ha)	60.9c	79.8b	94.9ab	101.6a	71.8b	78.4b
% Ndff	-	35.1c	48.6b	72.6a	49.7b	-
Total Fert. Uptake (kg N/ha)	-	28.0c	42.9b	76.8a	32.9c	-
% NUE	-	28.0	21.4	25.6	11.0	-
WUE (kg/ha-cm)	142.1d	176.5c	221.6a	210.7b	123.0e	124.8[e]

[x] Values in rows followed by the same letter are not significantly different at the 0.05 probability level.
[xx] Total amounts of N applied were 150, 300 and 450 kg N/ha, for 50, 100 and 150 mg N/L treatments, respectively.

TABLE IXa. DRY MATTER YIELD OF EGGPLANT (t/ha)

	Nitrogen rate (mg N/L)				Soil application	Slow release
	0	50	100	150	100	100
Leaves	0.4	0.6	0.5	0.5	0.5	0.6
Stem	1.4	1.91	1.9	2.0	1.8	2.1
Fruit	0.2	0.3	0.2	0.2	0.2	0.2

TABLE IXb. TOTAL N UPTAKE BY EGGPLANT (kg N/ha)

	Nitrogen rate (mg N/L)				Soil application	Slow release
	0	50	100	150	100	100
Leaves	16.4	26.8	23.9	21.4	21.5	22.7
Stem	11.2	21.9	27.3	31.8	23.1	19.0
Fruit	4.8	8.5	5.8	6.8	7.2	5.3

TABLE IXc. %Ndff

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Leaves	17.7	37.6	48.3	17.2
Stem	23.4	33.9	41.2	12.9
Fruit	23.2	36.0	53.1	11.5

TABLE IXd. FERTILIZER N UPTAKE BY EGGPLANT (kg N/ha)

	Nitrogen rate (mg N/L)			Soil application
	50	100	150	100
Leaves	4.74	8.99	10.33	3.7
Stem	5.12	9.25	13.10	2.98
Fruit	1.97	2.09	3.61	0.83

TABLE IXe. AVERAGE TOTAL MARKETABLE AND DRY MATTER YIELD, TOTAL N, % Ndff, % NUE AND WUE BY EGGPLANT (1997-1998)

Eggplant	Nitrogen rate^{xx} (mg N/L)				Soil appl.	Slow rel.
	0	50	100	150	100	100
Marketable Yield (t/ha)	62.4d^{x}	91.7ab	93.8a	87.1b	81.9bc	76.1c
Total D.M. (t /ha)	1.99b	2.77a	2.66a	2.65a	2.63a	2.85a
Tot. N (kg N/ha)	32.4c	57.2ab	57.0ab	60.0a	51.8b	47.0b
% Ndff	-	20.7c	35.7b	45.1a	14.5d	-
Total Fert. Uptake (kg N/ha)	-	11.8c	20.3b	27.1a	7.5d	-
% NUE	-	59.0a	50.8ab	45.2b	18.8c	-
WUE (kg/ha-cm)	143.5c	210.9a	215.7a	200.3ab	186.3b	175.0b

^{x} Values in rows followed by the same letter are not significantly different at the 0.05 probability level.

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CUCUMBER N NEED UNDER PROTECTED CULTIVATION USING ^{15}N-LABELLED UREA

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Abstract

To measure the N uptake and utilisation by plants, labelled ^{15}N has been used. In this paper ^{15}N-labelled urea was applied to cucumber under protected cultivation for two seasons, 1996/97 and 1997/98. Four levels of urea-N (0, 200, 400 and 600 kg N ha^{-1}) were used in a complete randomised block design with 8 replicates. The experiment was conducted in the UAE at the Hurnraniyah Agriculture Research Station (HARS) in collaboration with the International Atomic Energy Agency (IAEA). From the obtained results it was clear that the average optimal fertiliser rate was 200 kg N ha^{-1}. The N yield in the plant dry matter (fruits, shoots and roots) was 6.13 g N/plant under the specific experimental conditions (the area per plant was 1.23 m^2). Using ^{15}N, it was found that the fertiliser N yield obtained for the same plant parts was 1.82 g N/plant.

1. INTRODUCTION

Fertiliser use efficiency is a quantitative measure of the actual fertiliser uptake by the plant from a particular fertilised nutrient in relation to the amount of the same nutrient added to the soil [1]. However, it is the combination of different production strategies in a particular agricultural system that results in greater yields when the input for production is optimised. As such, input by fertilisers, if correctly used, have a marked contribution to an increased crop yield. Fertilisers, when used in combination with high yielding varieties and adequate irrigation water, can lead to a higher yield [2].

In Syria, a 2-year field experiment was carried out using ^{15}N-labelled urea to study the mechanism of N-losses and uptake by wheat [3]. Under sandy soil conditions, for example, it was estimated that losses of applied N was as high as 49% [4]. Under flooded conditions, Hamissa et al. [5] reported that the N recovery by rice ranged between 10% and 30% depending on the method of application. As a matter of fact introducing ^{15}N-labelled fertilisers permits direct measurement of fertiliser uptake by the different parts of the crop with no interaction of crop yield or responses to N fertilisation.

This paper discusses the results of trials on cucumber fertilisation under protected cultivation carried out in the United Arab Emirates (UAE) at the Humraniyah Agriculture Research Station (HARS) in collaboration with the International Atomic Energy Agency (IAEA). The experiment was conducted during the seasons 1996/97 and 1997/98, having as its main objective the use of ^{15}N (in our case ^{15}N-labelled urea) in a study related to soil fertility and plant growth to obtain maximum (optimum) N-level for maximising the cucumber yield.

2. MATERIALS AND METHODS

A two-year study was established at the Humraniyah Agricultural Research Station. The climate of the station is characterised by arid and semi-arid conditions. Maximum temperature ranges from 24° to 42°C. Maximum relative humidity ranges from 70% to 89% with an average annual rainfall varying between 100 mm to 120 mm.

The soil is medium textured varying from sandy loam to loamy sand with a marked deficiency in N content due to lack of organic matter being less than 0.1%. The P and K content is low. The $CaCO_3$ content is rather high ranging from 30% to 40%. The pH is about 8.2 and the EC may reach 4 dS/m.

Four levels of N (0, 200, 400 and 600 kg N ha^{-1}) with 8 replicates arranged in a completely randomised block were applied on 6.13 m^2 micro plots grown by cucumber. Fixed rates of P and K were applied (300 and 450 kg. ha^{-1}, respectively). Organic matter was applied on all four treatments at a rate of10 ton ha^{-1}. Each plant was irritated by a dripper having a discharge of 4 L/h. Nitrogen was added as urea, P as phosphoric acid (80%) and K as potassium sulphate, depending on the different treatments. ^{15}N-enriched urea (1.36% a.e.) was added to each cucumber plant through a plastic bottle hanging one each plant. The solution was prepared in different concentration depending on the treatment. It reached each plant via a plastic tube. Soil sampling was carried out at different depths (0-15, 15-30, 30-45 cm). The soil fertility level, salinity status and pH values were measured before and at the end of the experiment (Table I). At each picking, plant samples of the fruits related to the ^{15}N-labelled urea application were taken. At the end of the experiment, the whole plant including shoots and roots was harvested, oven-dried at 65°C and analysed for ^{15}N. The analysis was done by the IAEA laboratory in Vienna, Austria.

TABLE I. SOIL ^{15}N (BEFORE PLANTING AND AT HARVEST)

Sample No.	N rates (kg ha^{-1})	Depth (cm)	Description	pH	ECE (mmho/cm)	Mineral N	PO_4^{-3}-P	K Am-Ac
						ppm		
1		0-15	Mixed sample	7.9	3.47		50	100
2		15-30	before planting	8.0	3.07		40	110
3		30-45		8.1	2.26		30	115
1	0	0-15	Mixed sample	7.9	4.23	3.2	40	83
2	0	15-30	(under dripper)	8.1	2.97	2.1	30	110
3	0	30-45	Harvest	8.3	2.54	2.1	20	120
4	200	0-15		8.0	3.6	2.1	40	83
5	200	15-30		8.0	3.1	2.2	25	103
6	200	30-45		8.3	2.4	2.3	15	108
7	400	0-15		7.9	3.6	2.5	50	88
8	400	15-30		8.0	3.0	2.1	40	88
9	400	30-45		8.2	2.6	4.3	25	120
10	600	0-15		7.9	3.5	2.6	40	83
11	600	15-30		8.1	2.6	1.5	40	95
12	600	30-45		8.2	2.5	3.9	20	110

3. RESULTS AND DISCUSSION

Table II shows that the average cucumber yield (kg/plant) at different levels of N clearly responded to the N-fertilisation, with a significant difference between the different treatments. However, the levels of 200 kg N ha^{-1} and 400 kg N ha^{-1} showed no significant difference in cucumber yield. It shows, therefore, that the rate of 200 kg N ha^{-1} can be considered as the best N application level for cucumber under protected cultivation.

TABLE II. AVERAGE CUCUMBER YIELD (KG/PLANT) UNDER NORMAL UREA APPLICATION

Treatment (kg ha-1)	1st season (Nov. 96-Mar. 98) (kg/plant)	2nd season (Nov. 97-Mar. 98) (kg/plant)	Mean yield (kg/plant)
0	3.2	3.4	3.3
200	4.9	5.9	5.4
400	4.5	5.6	5.1
600	4.3	4.8	4.6

However, significant differences in cucumber yield were observed in the ^{15}N labelled urea treatments (Table III).

From the plant dry matter analysis of the fruits, shoots and roots it was seen that the total N required by the crop was within an optimal range. It was distributed among the plant parts as follows: fruits > shoots > roots (Table IV).

Table V shows the results of the %^{15}N derived from the labelled urea in the different plant parts (roots, shoots, fruits).

The following data were used to calculate the uptake of labelled urea N:

1. natural abundance: 0.37 % ^{15}N
2. abundance of the applied fertiliser: 1.36%
3. N derived from the fertiliser (%Nddf) = (%^{15}N a.e. in the plant / %^{15}N a.e. in the fertiliser) × 100

The basic yield and N uptake parameters for the 200 kg N ha^{-1} are given in Table VI.

TABLE III. AVERAGE CUCUMBER YIELD (KG/PLANT) USING ^{15}N LABELLED UREA

Treatment (kg ha^{-1})	1st season (kg/plant)	2nd season (kg/plant)	Mean yield (kg/plant)
0	2.8	3.6	3.2
200	3.5	4.7	4.1
400	4.1	5.3	4.7
600	3.4	4.5	4.0

TABLE IV. AVERAGE TOTAL N (%) UNDER NORMAL UREA APPLICATION

Treatments (kg N/ha^{-1})	% N 1st season			% N 2nd season		
	Roots	Shoots	Fruits	Roots	Shoots	Fruits
0	1.68	1.97	2.35	1.48	1.92	2.54
200	2.21	2.20	2.64	1.58	2.09	2.76
400	1.96	2.21	2.71	1.78	2.36	3.10
600	1.99	2.35	2.70	1.93	2.35	3.10

TABLE V. AVERAGE NITROGEN PERCENTAGE (% ^{15}N) FROM THE LABELLED UREA

Treatments (kg N/ha-1)	% ^{15}N 1st season			% ^{15}N 2nd season		
	Roots	Shoots	Fruits	Roots	Shoots	Fruits
0	0.015	0.028	0.086	0.010	0.010	0.010
200	0.910	0.790	0.780	0.680	0.680	0.660
400	1.145	1.010	0.980	1.060	1.040	1.110
600	1.130	1.060	0.820	0.960	1.010	1.040

TABLE VI. EXPERIMENTAL DATA

Plant part	Dry matter yield (g/plant)	Total N (%)	N yield (g/plant)	Nddf (%)	Fertiliser N yield (g/plant)
Fruits	162	2.76	4.50	29	1.31
Shoots	75	2.09	1.60	31	0.50
Roots	1.5	1.58	0.03	31	0.01
Total			6.13		1.82

Plant area (1.75 m × 0.70 m) = 1.23 m2
% Ndff (weighted average) = (1.82 / 6.13) × 100 = 30.

Table VI shows that the N yield of the cucumber plant (fruits, shoots and roots) was 6.23 g N/plant, the area occupied per plant being 1.23 m^2. The fertiliser N yield for the same plant parts was 1.82 g N / plant per 1.23 m^2. The % Ndff (weighted average) was 30. The results of this experiment are based on the data obtained per plant in order to avoid the interaction between the different sources of N (normal urea and ^{15}N-labelled urea). This is the reason why the plants were not spaced according to the standard cucumber spacing ($\leq$ 0.50 m^2). The same ^{15}N isotope technique will be repeated for studies dealing with N losses including volatilisation, N movement in the soil and biological N fixation.

4. CONCLUSION

From the results of this study it is clear that, using ^{15}N-labelled urea, that the average optimum fertiliser rate for cucumber under protected cultivation is about 200 kg N ha^{-1}. The data presented in this paper show that the N yield in the different cucumber plant parts (fruits, shoots and roots) was 6.13 g N/plant under the specific experimental conditions (notably the plant area). The fertiliser N yield for the same plant parts was 1.82 g N/plant.

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