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**

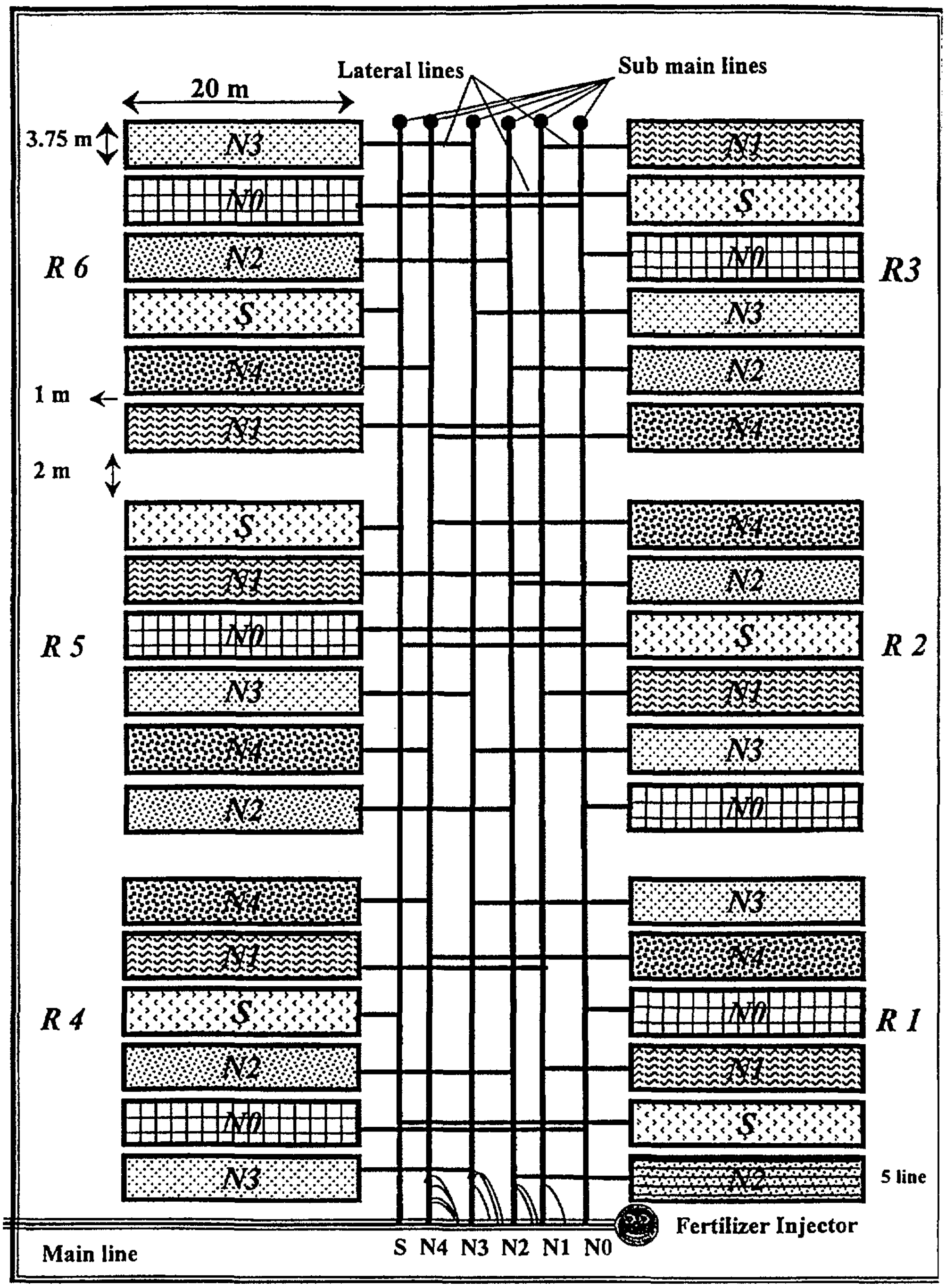

Figure 1. Experimental layout. Hama, 1995–1998.

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).

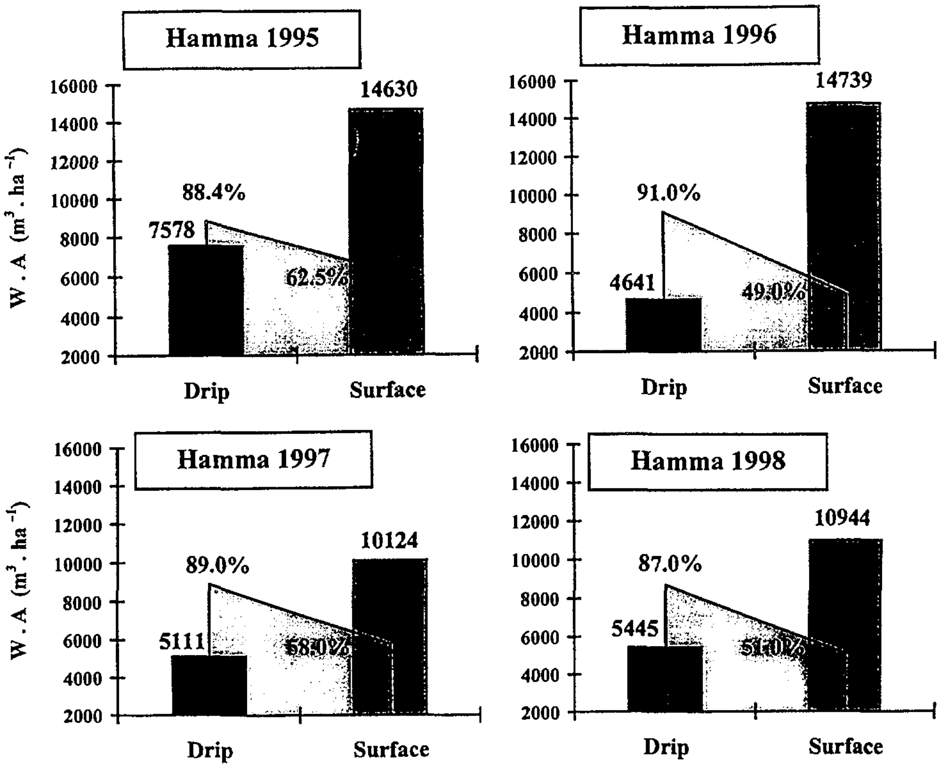

Figure 2. Effect of irrigation methods on water application 95-98.

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 kg ha^{-1}	Total N %	N-uptake kg ha^{-1}	Ndff %	N-fert yield kg ha^{-1}	NFUE %
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 kg ha^{-1}	Total N %	N-uptake kg ha^{-1}	Ndff %	N-fert yield kg ha^{-1}	NFUE %
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 kg ha^{-1}	Total N %	N-uptake kg ha^{-1}	Ndff %	N-fert yield kg ha^{-1}	NFUE %
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 kg ha^{-1}	Total N %	N-uptake kg ha^{-1}	Ndff %	N-fert yield kg ha^{-1}	NFUE %
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.

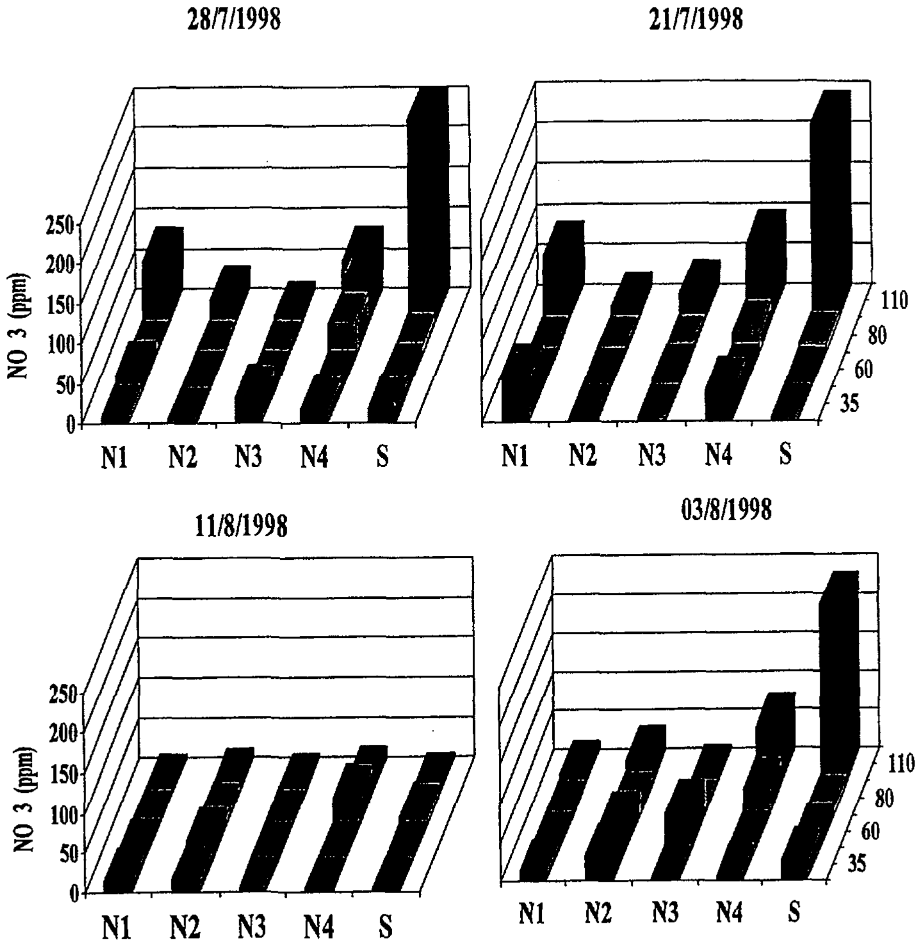

Figure 3. Effect of irrigation method on soil solution nitrate. 1998.
Drip: 09/5/98–03/6/98–27/6/98 –09/7/98–21/7/98–29/7/98–04/8/98
Surface: 09/5/98–16/6/98–09/7/98

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