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

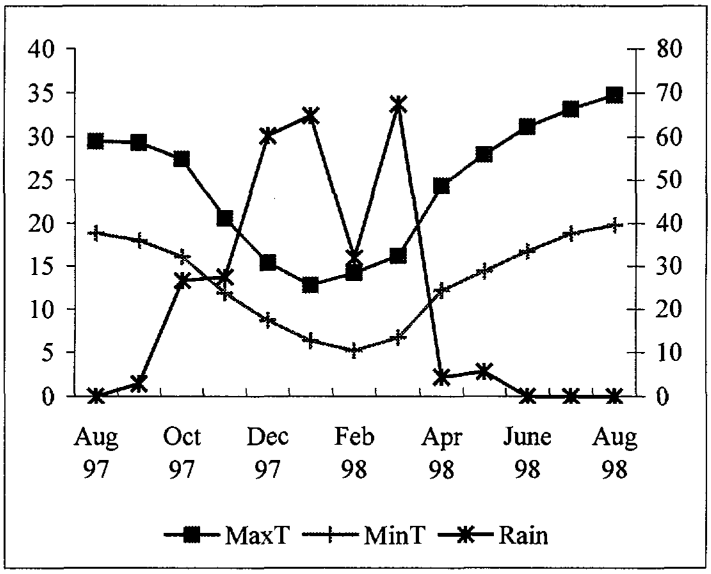
The area of the research site is characterized by an aridic moisture regime. The rainy season extends from October to April where the highest amount of precipitation occurs during January and March (Fig. 1). The soil of the research site is characterized by being alkaline, calcareous and fine textured. 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



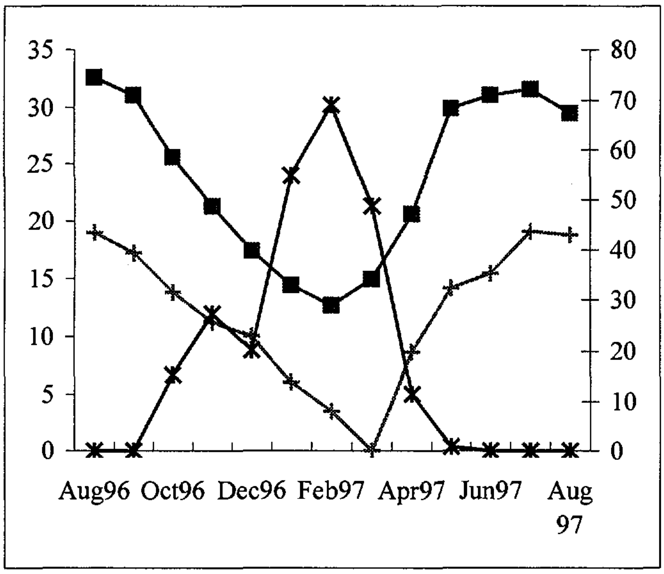


Fig. 1. The average monthly temperature and total precipitation during the growing seasons (1996/97 & 1997/98).

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.

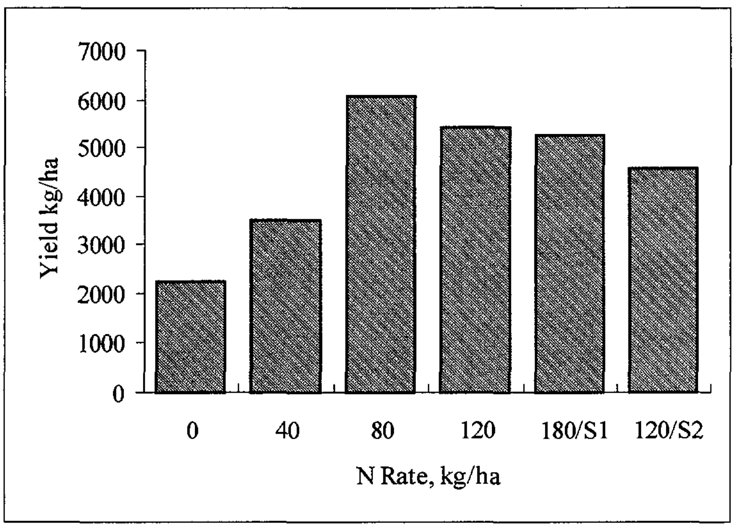


Fig. 2. Fresh weight of marketable heads per ha as affected by N rates.

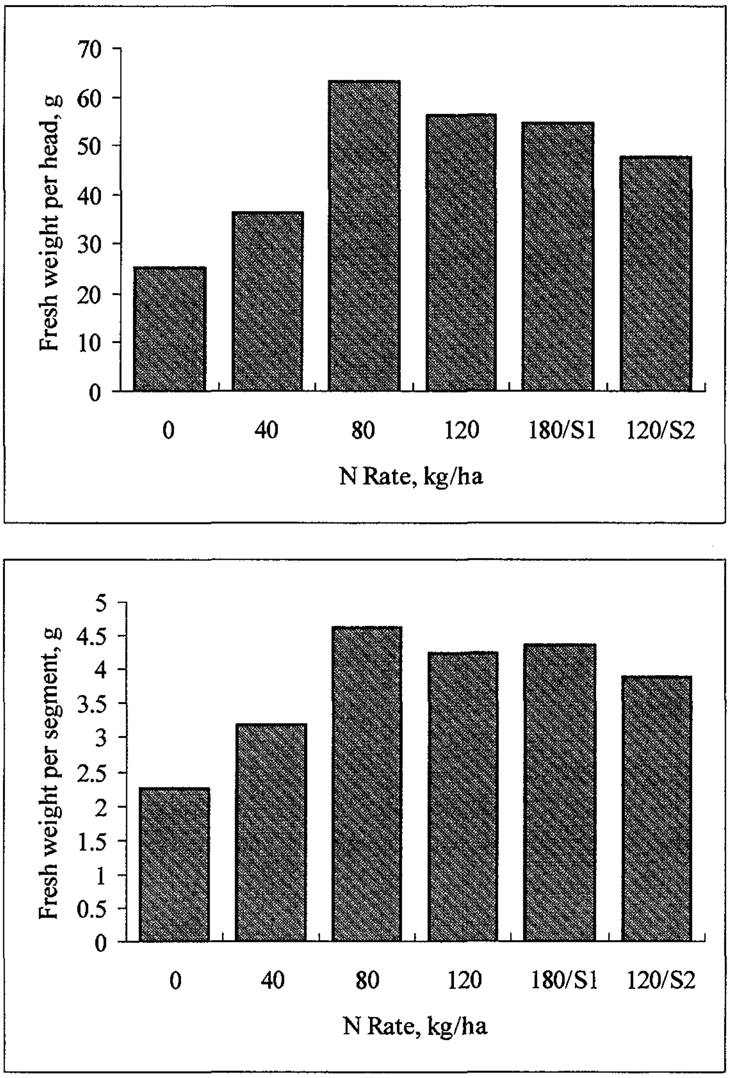


Fig. 3. Fresh weight per head and per segment as affected by N rates.

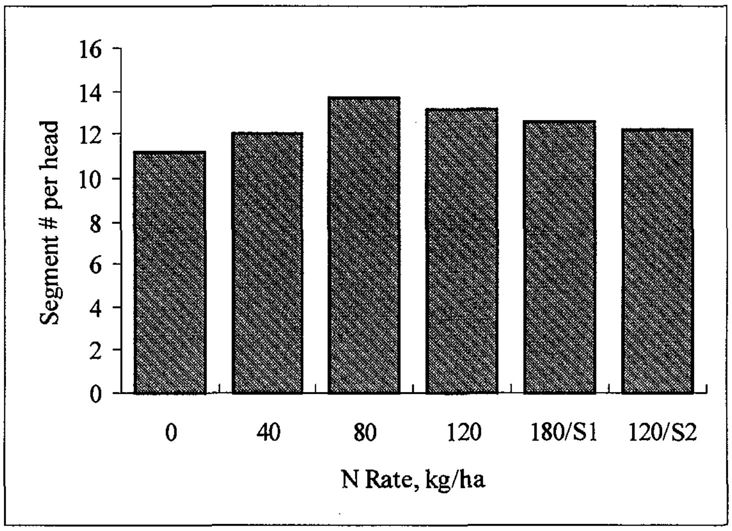


Fig. 4. Number of segments per head as affected by N rates.

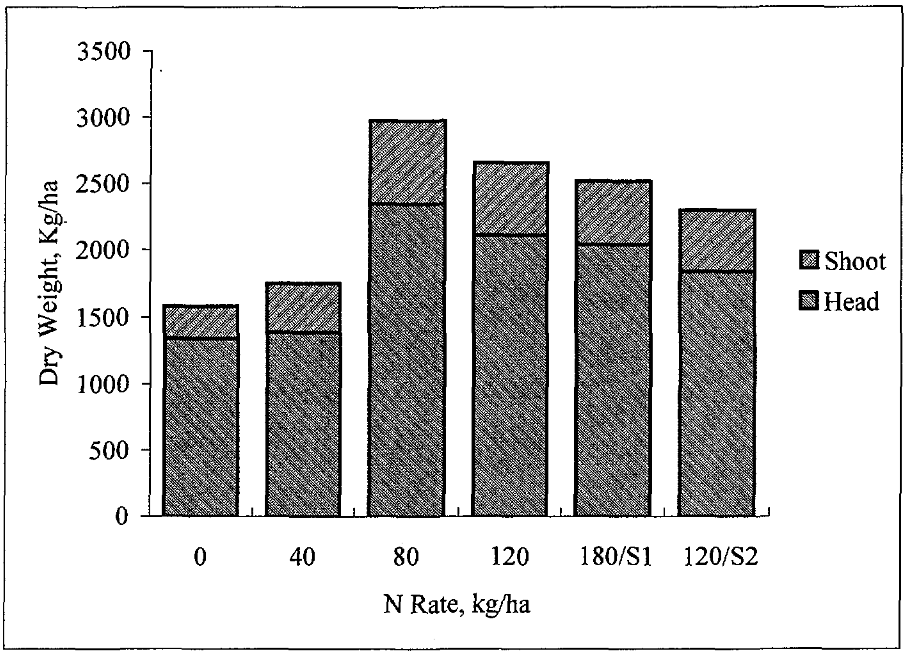


Fig. 5. Dry weight of segments, segment membrane and shoot per ha as affected by N rates.

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.

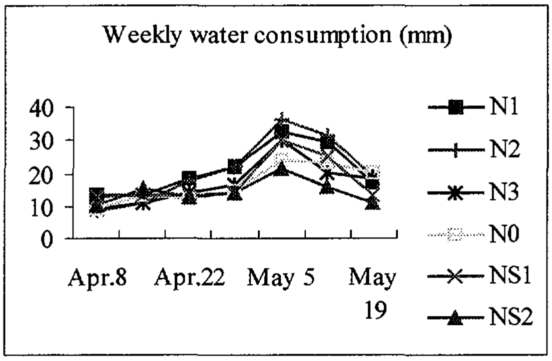


Fig. 6. Weekly water consumption, 1997.

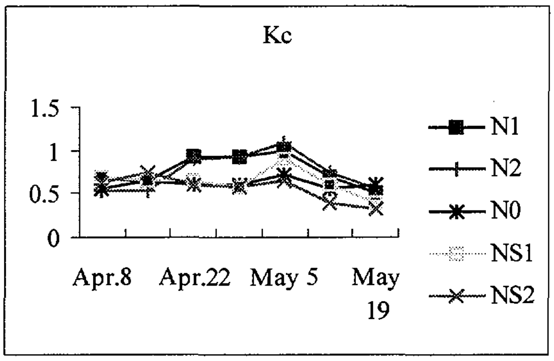


Fig. 7. Crop coefficient (Kc) , 1997.

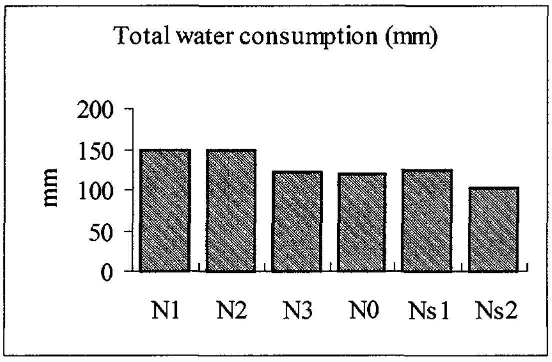


Fig. 8. Total water consumption, 1997.

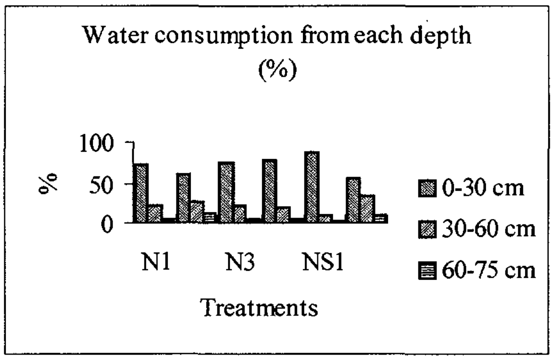


Fig. 9. Percentage of water consumption with soil depths, 1997.

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).

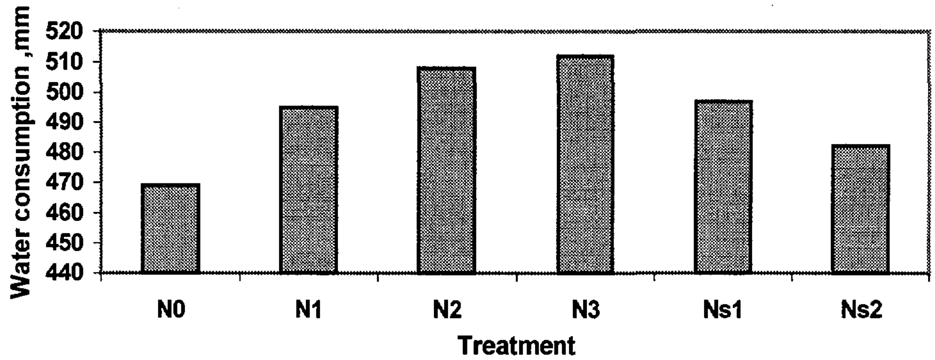


Fig. 10. Seasonal water consumptive use, 1998.

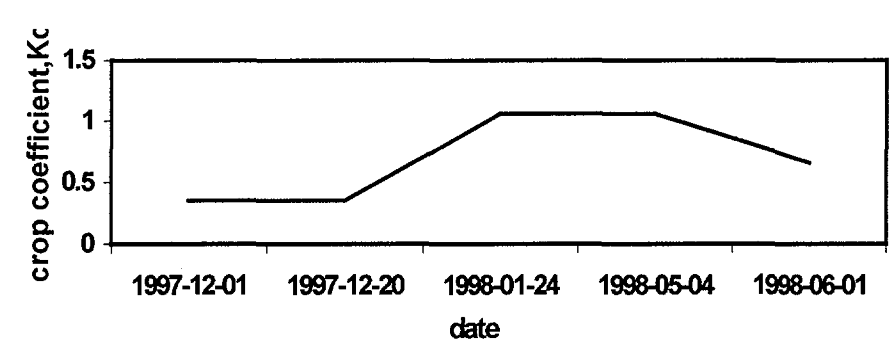


FIG. 11. Garllic crop coefficient, 1998.

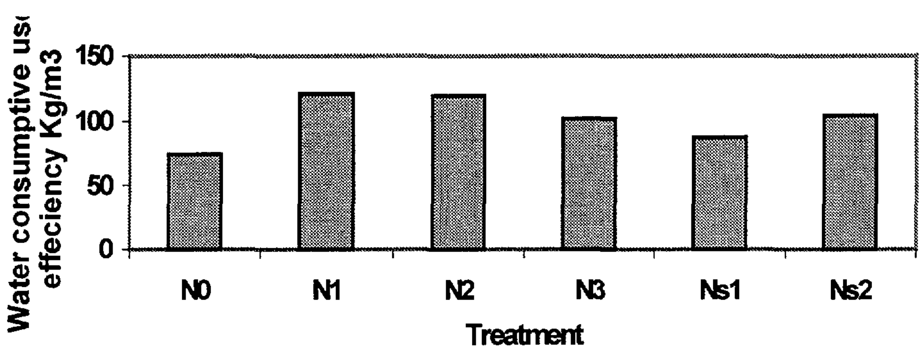


FIG. 12. Garlic water consumptive use efficiency (kg/m^3) 1998.

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