Evaluation of fertilizer and water balance under vegetable-fertigation system using nuclear techniques

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Abstract

Water and nitrogen are main limiting factors of agricultural production in semiarid regions. Fertigation, is the application of fertilizers through irrigation water, where time and rate of water and fertilizer application are precisely controlled and therefore, more use efficiency of water and N. The objective of this study was to determine crop response, nutrient uptake and water and fertilizer use efficiency under fertigation system. Field experiment was conducted where the following treatments were studied in an randomized complete block design with four replications: Zero N (N0), 50 (N1), 100 (N2) and 150 (N3) mg kg^{-1} N in the irrigation water. Additional soil application treatment (NS) equivalent to the N2 was included. The fertilizers were either injected into irrigation water by means of an injection pump for the fertigation treatments or applied directly to the soil followed by irrigation for the soil application treatment. Squash was planted in plots with four rows per plot. Each plant row has its own irrigation line and each plant its own dripper. Irrigation was applied to replenish 80% of the Class A pan evaporation twice a week. Neutron probe readings were taken before and after each irrigation at 15, 30, 45, 60 and 90 cm soil depth. Labeled N fertilizers (^{15}N) were applied to a microplots which contained four plants within each plot. At harvest, plant samples were taken from the microplots for the ^{15}N measurements and from the mainplot for yield determination and chemical analysis. Yield increased with increasing N rates in the range from N0 to N2. The soil application gave higher yield than the N0 treatment but lower than other treatments. The N2 gave higher yield than other treatments. Shoot and fruit dry weight had similar trend as the yield. Nitrogen concentration in fruits and leaves was higher with fertigation where the lowest value obtained with N0. Similar trend was obtained for the total N uptake. Nitrogen derived from fertilizers (Ndff) increased with compared to soil application treatment. Nitrogen uptake dff had similar trend as the Ndff. Nitrogen use efficiency (NUE) by fruits as determined ^{15}N was lowest with soil application than with fertigation treatments and tends to decrease with increasing N fertigation rates. NUE calculated by the difference method were higher than that determined by ^{15}N data. Phosphorus use efficiency (PUE) was enhanced by N application due to the. synergistic effect on P uptake. Water consumption increased with increasing N rates. Water use efficiency increased with N application and was higher with fertigation treatment. Water depletion was maximum in the 30 cm, suggesting the depth of maximum roots growth. Soil pH and soil organic matter were not affected, while soil salinity was higher with N application especially at the top 15 cm. Soil P increased mainly in the top soil due phosphoric acid application to all plots. It can concluded that yield, NUE and WUE increased with N fertigation than

with soil application. The difference method tend to give higher values for the NUE compared to that measured by ^{15}N data.

Keywords: fertigation, nuclear techniques, nitrogen use efficiency, water use efficiency

Introduction

Water and nitrogen are main limiting factors affecting agricultural production in arid and semiarid regions. Improving the efficiency of these factors is, therefore, the target of a good management. The method of application of irrigation water or fertilizers are among the most important factors that affect the fertilizer use efficiency.

Fertigation, as a means for fertilizer application, is widely expanding all over the world especially in regions of limited water resources. Fertigation controls precisely the time and rate of both water and fertilizer application to any particular plant growth stage. This improves water and N use efficiency, minimize leaching and volatilization losses as well as ground water contamination with nitrate nitrogen (Mitchell, 1981; Anon, 1981; Feigin, 1982). Moreover, fertigation along with the advanced drip irrigation systems, the most efficient method of irrigation (Bernstein and Francois, 1973; Sammis, 1980), is more convenient and less expensive fertilization method compared to the traditional soil application methods (Gardner and Roth, 1984).

With fertigation, both time and rate of nutrients can be controlled, to meet the requirements of a crop at each physiological growth stage (Caldwell *et al.,* 1977; Papodopoulos, 1988). This decreases leaching and volatilization losses, improves the N utilization efficiency, and minimizes ground water contamination (Miller *et al.,* 1981; Papodopoulos, 1985). In addition, applying N fertilizer with the irrigation water is a more convenient and less expensive method compared to the traditional methods (Gardner and Roth, 1984). It has been reported that fertigation is the most efficient method of fertilizer application (Mitchell, 1981; Feigin, 1982). Papadopoulos (1988) reported that with fertigation high yield and good quality of potato could be obtained. On the other hand, the fertilizer use efficiency is affected by several factors such as the amount of irrigation water (Hargert *et al.,* 1978) and soil texture (Hagin and Tucker, 1982). Starck *et al.* (1993) reported that the responses of potato to split N application, with varying amounts of irrigation, were not similar. At all levels of irrigation they found that biweekly application of nitrogen produced higher yields than weekly N applications.

Mohammad *et al.* (1999) found that with fertigation high yield and high quality of potato were obtained. Quawasmi *et al.* (1999) found that with fertigation nitrogen can be provided according to the growth stages of pepper crops and N fertigation beyond the stages of maximum growth will not affect the growth and decrease the fertilizer use efficiency. Other researchers found that the fertilizer use efficiency was affected by the amount of irrigation water (Hergert *et al.,* 1978) and by split N application (Starck *et al.* (1993) who found that biweekly N application produced higher yields than weekly N applications at all irrigation levels.

Preplant application of N tend to stimulate the vegetative growth, increase the photosynthetic activity and to delay maturity and tuber growth of potato (Westermann and Kleinkopf, 1985). Good supply of N should be during all stages of growth. This can be achieved by fertigation and favorably reflected on the tuber growth and development (Hagin and Tucker, 1982).

It was reported by Keng *et al.* (1979) that fertigation with drip irrigation produced 16% higher pepper yields than broadcasting the fertilizers. In addition, fertigation alleviate the cost compared to conventional split application (Caldwell *et al.,* 1977). Drip irrigation, the most efficient method for irrigation (Bernstein and Francois, 1973; and Sammis, 1980), is considered also the most suitable for fertigation (Papodopoulos, 1985). Irrigation scheduling is an important factor controlling the efficient use of irrigation waters. Battikhi and Suwwan (1997) found that under plastic houses less water was needed to obtain the same tomato yield when irrigation scheduling was based on pan evaporation than on neutron probe. However, this phenomenon was not investigated in the open field and for other crops under fertigation systems and consequently are recommended to be studied.

Modern irrigation systems are already widely used in Jordan and continually expanding. These irrigation systems proved to increase water use efficiency and therefore decrease the losses of water by evaporation and leaching observed during the traditional irrigation systems. Moreover, Jordan is suffering from the scarcity of irrigation water resources. All these factors promoted the growing concerns 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 reevaluated to match the requirements and conditions created by this development. All elements of the fertilization program must also be reevaluated and tested to develop an updated guidelines for a proper fertilization recommendations for the major crops.

Summer squash is considered one of the main vegetable crops grown in Jordan. Water resources are very limited in Jordan especially in summer time, therefore, improving water use efficiency by irrigated summer crops is crucial. The high net return for the farmers by growing summer vegetable crops can be achieved only through higher use efficiency of irrigation water and fertilizers. This would increase crop production, increase N and water use efficiencies and decrease cost of fertilizer and minimize environmental pollution from chemical fertilizers

Little research has been conducted to manage fertilization and irrigation of squash under fertigation systems. The goal of this study was to increase water and fertilizer use efficiency. The specific objectives of this study are:

(1) Compare the conventional fertilization method with fertigation,

(2) Evaluate the water and nitrogen use efficiency of both methods of application,

(3) Estimate crop water requirements and evaluate water use efficiency as affected by methods of applications and rates of N fertigations and

(4) Evaluate plant N distribution and water and nutrient distribution in the soil profile.

Methodology

This study was implemented at the Research Center of 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 four replications of each treatment to achieve the above objectives:

(1) N0=Zero N application
(2) N1=50 mg kg^{-1} N in the irrigation water
(3) N2=100 mg kg^{-1} N in the irrigation water
(4) N3=150 mg kg^{-1} N in the irrigation water
(5) NS=Conventional 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 concentration of 50 mg kg^{-1} 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 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 the fertilizers into the irrigation water. One for application of nitrogen treatments (rates) and the other for the application of P.

Squash (cv. Hybrid Squash Scarlette) was planted on June 26, 1999 and harvested on September 15, 1999 for the first season and on April, 2000 and July 6, 2000 in the second season. Squash was planted at 40 cm between plants and 150 cm between rows. Plot dimensions were 6m x 5m. Each plot contained 4 rows each 6m long. Each row had its own irrigation line positioned near the plants. Emitters were spaced 40 cm apart in the irrigation line. Irrigation was applied to replenish 80% of the Class A pan evaporation twice a week.

Access tubes for Neutron probe reading were mounted in the middle of the second row of 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. 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 four plants within each plot. The microplots were fertigated through inverted bottles with drippers which simulate the drippers of the original irrigation line. The macroplots were fertigated with 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 2 mm sieve and were analyzed for physical and chemical properties. Some of the major characteristics of the soil before starting the experiment are shown in (Table). Soil samples were also taken from each plot at the end of the growing season and were treated similarly as mentioned above. Soil moisture content during the season was monitored using the Neutron Probe. Yield and yield components were determined after harvesting the crop. Plant shoot and fruit were analyzed for dry weight and NPK.

At harvest, plant samples were taken from the microplots were the labelled fertilizers were applied for the ^{15}N measurements. The two middle whole plants in each of the microplots were collected and samples were sorted into above ground vegetative biomass (shoot). Fruits were collected from each harvest and over dry it at 70 ^{o}C and at the end of the experiment all were fruit samples were ground to have a composite sample. Shoot samples were also oven dried at 70^{o}C and weighed to get the dry matter for each sample. Samples then were ground to pass 1mm sieve and stored for tissue analysis. Plant samples were collected and prepared according to the instructions for sampling for ^{15}N analysis

The yield was recorded from harvesting the middle two rows and the yield was calculated per one hectare area. Plant shoots and fruits samples taken from the macroplot receiving the non labeled nitrogen fertilizers were oven dried at 70°C and weighed to get the dry matter for each sample. Samples then were ground to pass 2 mm sieve and analyzed for nutrients.

Results and Discussions

The area of the research site is characterized by having an aridic moisture regime. The rainy season extends from October to April where the highest amount of precipitations occur during January and March. The soil of the research site is characterized by being alkaline, calcareous and fine textured soil. This soil also contain low organic matter, low soluble salts, moderate P content but adequate available form of K. General characterestics of the soil are shown in Table 1.

Table 1 Soil characteristics of the experimental site.

Soil properties	Units	Soil depth, cm		
		00 - 15	15 - 30	30 - 60
pH, 1:1	-	8.15	7.88	7.92
EC	dSm^{-1}	0.53	0.44	0.31
OM	%	0.90	0.56	0.32
$CaCO_3$	%	15.30	16.50	21.20
Total N	%	0.09	0.08	0.04
Olsen-P	$mg\ kg^{-1}$	9.61	7.23	3.52
K	$mg\ kg^{-1}$	650.00	620.00	430.00
CEC	$cmol\ kg^{-1}$	37.50	37.50	31.00
Texture	-	Silt Loam	Silt Loam	Silt Loam

The absolute amounts of N applied through the irrigation water were 0, 66, 132 and 198 kg N ha^{-1} for the N0, N1, N2, and N3 fertigation treatments and 130 kg N ha^{-1} for the base soil application treatment for the first season. In the second season the absolute amounts of N applied through the irrigation water were 0, 91, 182 and 273 kg N ha^{-1} for the N0, N1, N2, and N3 fertigation treatments and 192 kg N ha^{-1} for the base soil application treatment.

The amount of fertigation water (irrigation water with N fertilizers dissolved in it) applied were 1210 m^3/ha in the 1998/1999 season and 1820 m^3/ha in the 1999/2000 season. The absolute amount of P applied as phosphoric acid in the irrigation water were 39.4 and 57.6 kg P ha^{-1} for the 1998/1999 and 1999/2000 seasons respectively. The soil test values for K indicated the presence of adequate amount of this nutrient in the soil for normal growth. Therefore K was not applied. The amount applied in the NS treatment was 132 kg N ha^{-1} in the first season and 192 kg N ha^{-1} in the second season. The total amount of irrigation water applied were 1490 and 2330 m^3.ha for the first and second seasons respectively.

1998/1999 season

Yield and yield components

The fresh weight of fruits (yield) continued to increase with increasing N fertigation rates in the range from N0 to N2 (Table 2 and Figure 1). The soil application (NS) gave higher yield than the zero N treatment but lower than other treatments. The fresh weight per fruit was similar for all treatments except for the N0. The N2 treatment tends to give relatively the higher yield compared to other treatments. However the number of fruits per hectare has the same trend as the yield.

Table 2 Yield and yield components of squash as affected by the treatments, 1999.

Trts Code	t ha^{-1} Yield	x 1000 ha^{-1} Number	g fruit^{-1} Weight
N0	7.79	85.00	90
N1	9.53	89.25	107
N2	10.27	98.75	104
N3	9.79	96.42	102
NS	8.98	99.91	99

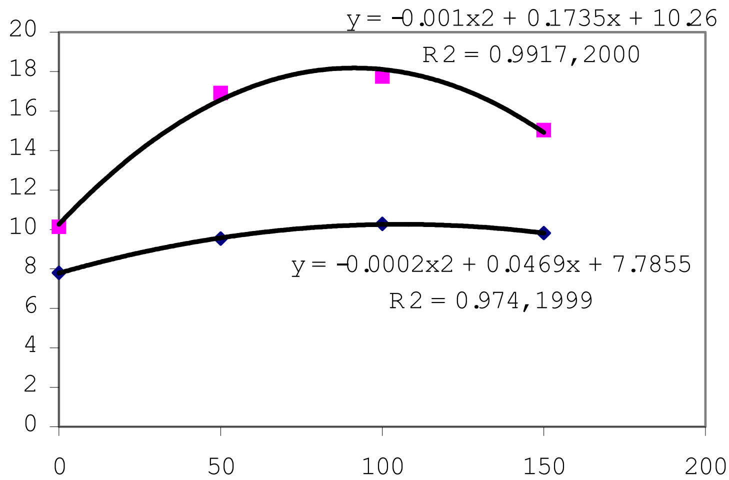

Figure 1 Squash yield for the 1999 and 2000.

Nitrogen utilization

Nitrogen utilization by fruits and leaves are presented in Table 3. 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. Nitrogen content was lower with soil application treatments. Similar trend was obtained for the total N uptake.

The Ndff value was the lowest for the soil application treatment. The soil application treatment gave Ndff value which was lower than the fertigated treatments for the whole plant (fruits and leaves). The N uptake dff for fruits and shoot had similar trend as the Ndff.

Table 3 Nitrogen utilization by squash, 1999.

Trt	kg ha^{-1}	Fruit N%	Fruit N15%	Shoot N%	Shoot N15%	Fruit Ndff%	Shoot Ndff%	Fruit dwt, kg ha^{-1}	Fruit kg ha^{-1}	Fruit Nup dff	Shoot dwt, kg ha^{-1}	Shoot kg ha^{-1}	Shoot NUP dff	Total Nup dff	Fertil. Util. %
N0	0	3.78		1.80				1155.8	45.49		618.2				
N1	66	4.43	2.00	3.48	2.28	35.04	39.84	1479.7	68.90	24.10	924.3	18.32	7.37	31.46	47.89
N2	132	4.68	2.46	3.65	3.59	43.07	45.37	2192.4	100.67	44.07	1283.8	33.21	15.41	59.48	45.27
N3	198	4.72	2.85	3.62	2.84	49.95	49.70	2069.8	93.65	46.34	1188.2	33.36	17.60	63.94	32.44
NS	128	4.29	1.55	2.98	1.91	27.10	33.46	1796.6	76.51	20.03	938.9	17.79	5.98	26.01	20.32

Fertilizer utilization by fruits was lowest for the soil application treatments compared to the fertigation treatments. No significant differences were obtained among fertigation treatments themselves. NUE and PUE using the difference method were also calculated for shoot and fruit during the growing season (Table 4). There values were higher than that determined by the 15N data. The PUE was enhanced by N application.

Water utilization

Daily squash water consumption was not greatly affected by treatments and it ranged between 0.5 mm during July after transplanting up to the maximum water consumption 2.7 mm which occurred in August. The total water consumption was 129.2, 133.2, 131.1, 138.4 and 139.4 mm for N0, N1, N2, N3 and Ns treatments respectively (Figure 2).

Monthly water consumption was the minimum of 24.3 mm in July for N0 treatment and the maximum of 65.5 mm in August for N3 treatment (Figure 3). The value for the mean treatments were 27.0, 61.5, and 43.9 mm for July, August, and September (Figure 4) indicating that the water consumption increased in August and then declined in September. This increased was due to increased in plant growth. The minimum weekly water consumption was 2.9 mm per week in the first week for Ns treatment and the maximum value was 18.5 mm per week at 9th week for N3 treatment.

Water use efficiency in terms of yield produced per unit of water was calculated. Two definitions were used according either to water applied to the field (application water use efficiency) or to crop water consumption (consumption water use efficiency). The application water use efficiency of fruit yield at different treatments was 5.3, 6.4, 6.9, 6.6, and 6.0 kg/m^3 for N0, N1, N2, N3, and Ns respectively (Figure 5). Consumption water use efficiency was 6.1, 7.1, 7.8, 7.0 and 6.9 kg/m^3 for N0, N1, N2, N3, and Ns, respectively (Figure 6). Weekly consumption water use efficiency for different treatments ranged from 13.4 to 12.8 kg/m^3 in the first week for N1 and N2. Then it decreased at the end of the season to reach 1.4 kg/m^3 in the 8th week.

Table 4 P and N utilization by summer squash during the summer growing season of 1999.

Treatments		%P	%N	DWT/ha	P-up/ha	N-up/ha	PUE	NUE
Code	kg N ha^{-1}	Shoot at start of flowering (July 31, 1999)						
N0	0	0.286	3.557	0.932	2.617	32.803	0.631	-
N1	66	0.32	3.94	1.019	3.261	40.13	2.055	11.157
N2	132	0.36	4.453	1.097	3.835	48.46	3.514	11.92
N3	198	0.301	4.497	1.178	3.492	52.572	2.641	10.033
NS	130	0.53	4.52	0.975	5.109	43.997	6.747	8.746
Shoot at mid fruiting period (Aug. 24, 1999)								
N0	0	0.217	2.367	1.461	3.173	34.581	1.833	-
N1	66	0.189	2.78	2.002	3.813	55.493	3.456	31.839
N2	132	0.185	2.637	2.043	3.652	52.126	3.049	13.356
N3	198	0.195	3.083	1.874	3.66	57.609	3.068	11.687
NS	130	0.232	2.84	1.699	3.916	46.654	3.718	9.432
Fruit at mid fruiting period (Aug. 24, 1999)								
N0	0	0.682	4.467	0.416	2.826	18.616	0.952	-
N1	66	0.531	5.187	0.808	4.232	41.742	4.521	35.21
N2	132	0.578	5.103	0.826	4.775	42.125	5.899	17.896
N3	198	0.561	5.723	0.789	4.326	45.308	4.76	13.546
NS	130	0.594	4.58	0.734	4.35	33.497	4.819	11.625
Shoot at last harvest (Sep. 19, 1999)								
N0	0	0.322	1.77	1.255	3.999	22.181	3.928	-
N1	66	0.275	2.393	2.169	5.904	50.744	8.764	43.488
N2	132	0.237	3.333	2.016	4.779	67.235	5.909	34.298
N3	198	0.253	3.307	2.209	5.526	72.967	7.805	25.774
NS	130	0.246	2.723	1.99	4.838	53.789	6.058	24.694
Fruit at last harvest (Sep. 19, 1999)								
N0	0	0.49	3.597	0.747	3.652	27.035	3.049	-
N1	66	0.459	3.853	1.51	6.942	57.682	11.399	46.661
N2	132	0.43	4.393	1.612	6.913	70.923	11.325	33.41
N3	198	0.458	4.457	1.427	6.523	63.646	10.336	18.58
NS	130	0.396	4.17	1.315	5.189	54.978	6.949	21.83

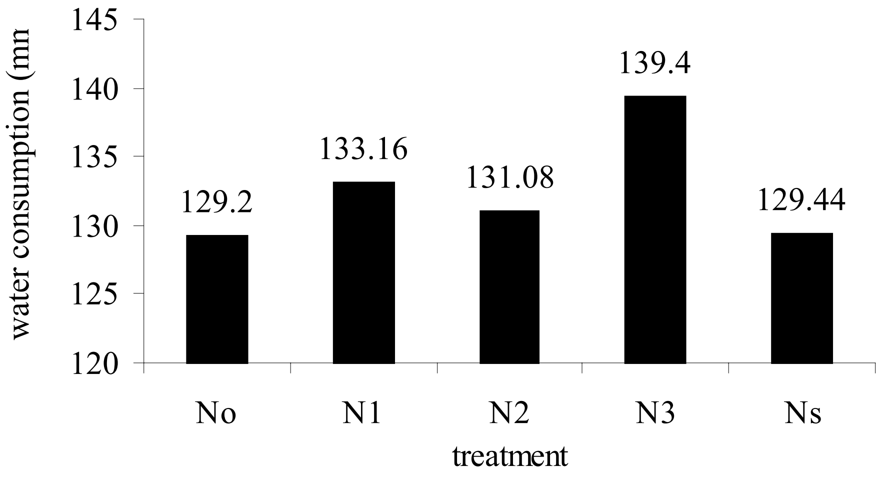

Figure 2 Squash water consumption, 1999.

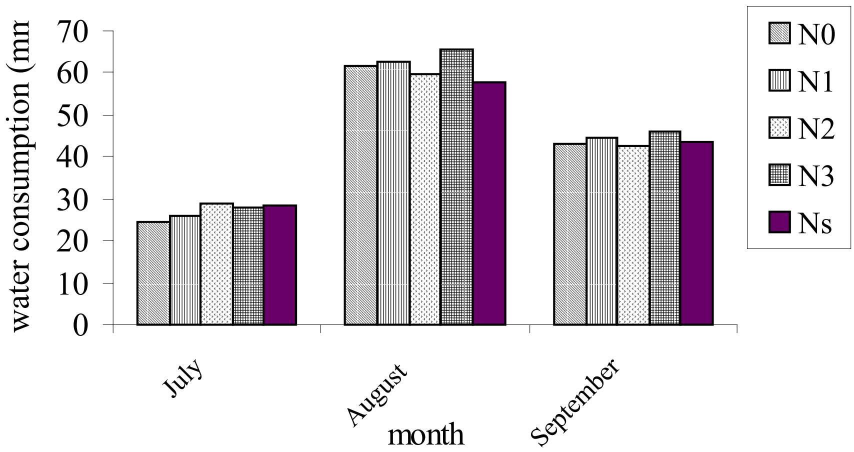

Figure 3 Squash monthly water consumption, 1999.

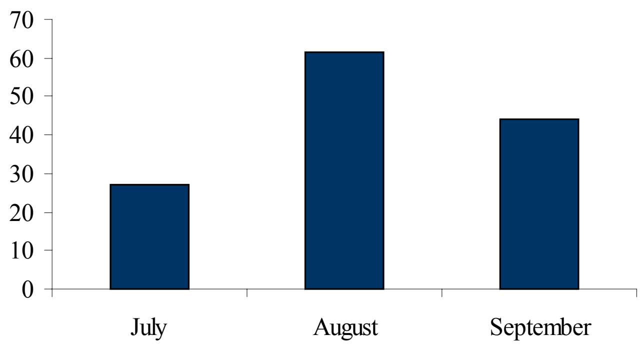

Figure 4 Squash monthly water consumption, 1999.

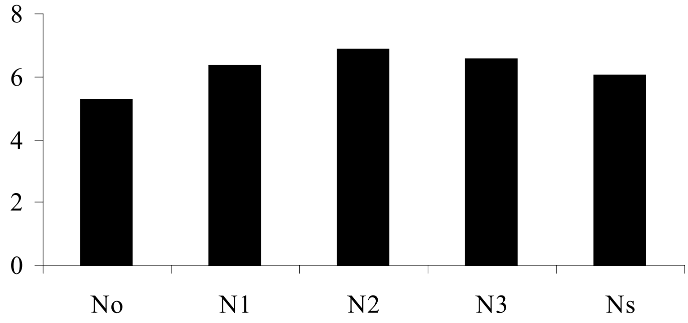

Figure 5 Application water use effeciency, 1999.

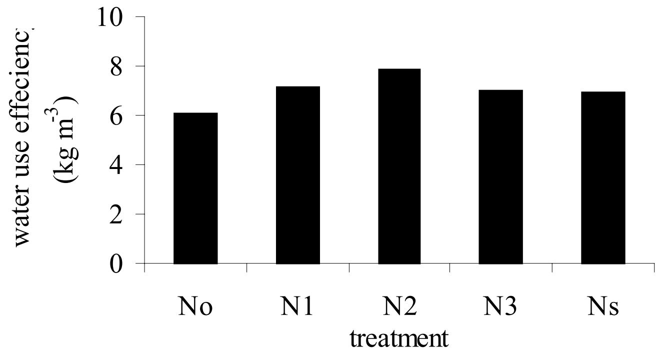

Figure 6 Crop water use effeciency, 1999.

Squash crop coefficient was 0.29, 0.71, 0.95, and 0.72 for the initial, developmental, mid seasonal and maturity stages respectively (Figure 7 and Figure 8).

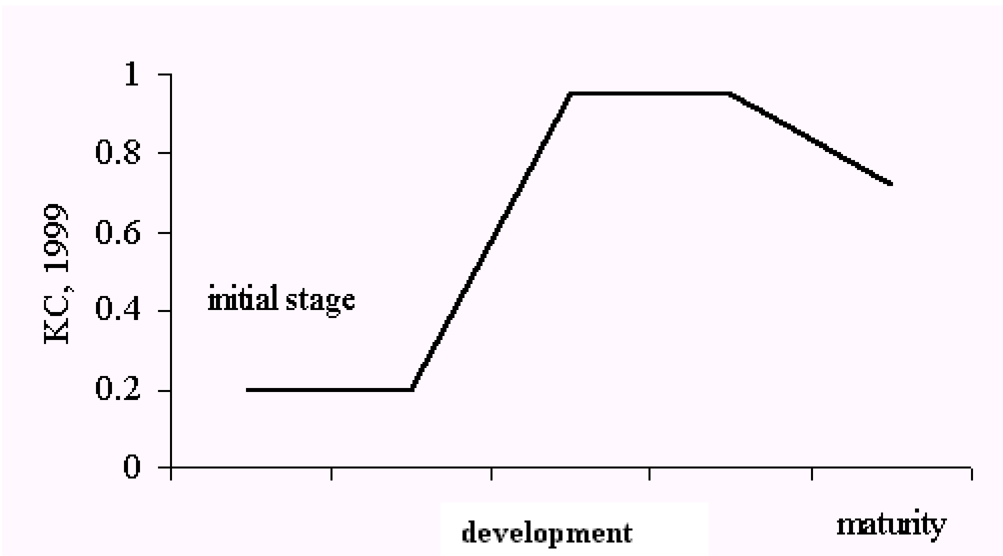

Figure 7 KC, 1999.

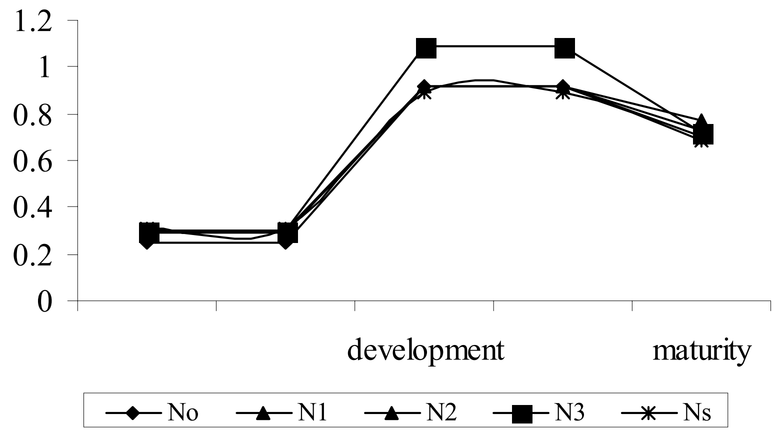

Figure 8 KC, 1999.

Water extraction from different soil depths was the highest (greater than 70%) at the top 30 cm soil depth (Figure 9). On the other hand, the percentage of water extraction from the lower depth 75-90 cm was not exceeding 2%. Water extraction from different depths were 72%, 14%, 8%, 4% and 2% from 0.0-30, 30-45, 45-60, 60-75, and 75-90 cm respectively. The amount of water absorption from the upper 30 cm soil depth was 88.2, 100.3, 92.5, 100 and 93.9 mm for N0, N1, N2, N3, and N0 treatment, respectively (Figure 10). Plant water extraction from different depth was 237.5, 45.18, 27.44, 13.68 and 7.6 mm of water from 0.0-30, 30-45, 45-60 60-75, and 75-90 cm respectively. According to these results it can be concluded that most of plant roots were at the upper 30 cm of the soil depth.

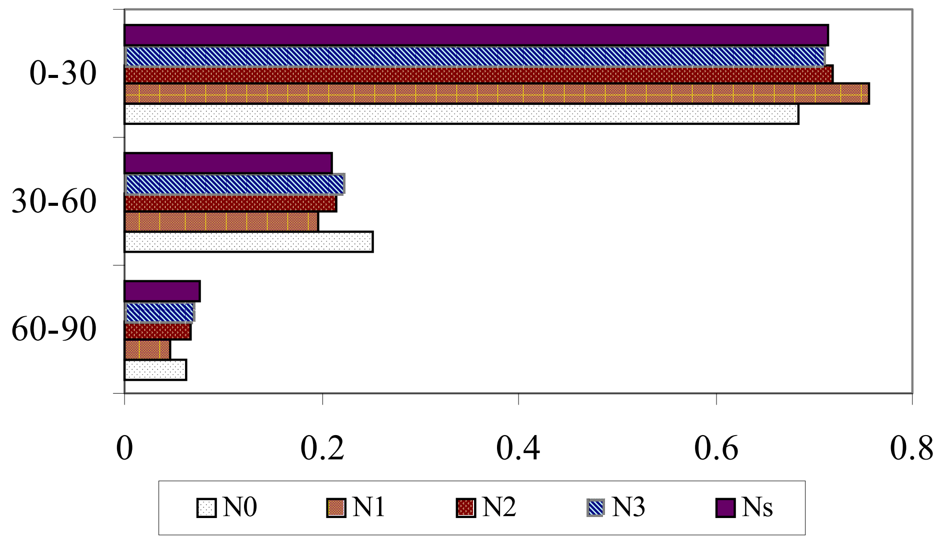

Figure 9 Soil moisture exctraction, 1999.

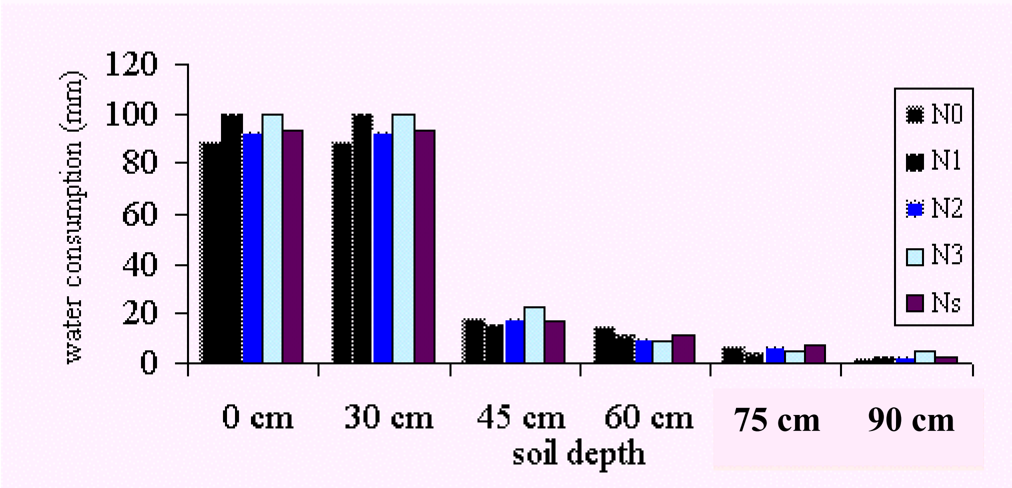

Figure 10 Water consumption at defferient depth under defferient treatment.

1999/2000 season

Yield and yield components

All fertigation treatments gave high yield compared to the zero N treatment and soil application (Table 5 and Figure 1) Yield tend to decrease with the highest N fertigation rate. He N2 treatment gave the highest yield. The number of fruits per hectare had similar trend as the yield. However, the weight of one fruit was lowest for the N0 treatment. It should also be mentioned that, the yield and yield components were higher in the second year due to the more favorable climatic conditions prevailed in the second season.

Table 5 Yield and yield components, 2000.

Trts	Yield	Number	Weight
	t ha^{-1}	1000 ha^{-1}	gL^{-1}fruit
N0	10.14	117.3	0.087
N1	16.92	141.0	0.120
N2	17.75	150.5	0.118
N3	15.03	129.0	0.117
NS	14.25	122.0	0.117

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 (Table 6). Nitrogen content was lower with soil application treatments. Similar trend was obtained for the total N uptake.

The nitrogen uptake derived from fertilizers (Ndff) were the higher with fertigation compared to soil application treatments. The single soil application treatment gave lower value 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 Ndff value which was lower than the fertigation treatments for the whole plant (fruits and leaves). The N uptake dff for fruits and shoot had similar trend as the Ndff.

Table 6 Nitrogen utilization by squash, 2000.

Trt	kg ha-1	Fruit N%	Fruit N15%	Shoot N%	Shoot N15%	Fruit Ndff%	Shoot Ndff%	Fruit dwt, kg ha-1	Fruit kg ha-1	Fruit Nup dff	Shoot dwt, kg ha-1	Shoot kg ha-1	Shoot NUP dff	Total Nup dff	Fertil. Util. %
N0	0	3.98	0.00	2.27	0.00			1235.2	49.11		1394.1				
N1	91	4.96	2.53	3.49	2.44	47.19	45.40	2039.1	101.15	47.80	1322.3	32.38	14.92	62.72	68.93
N2	182	5.42	3.07	3.62	3.03	57.25	56.46	2207.5	119.52	67.63	1339.5	41.50	25.08	92.71	50.94
N3	264	5.34	3.61	3.52	3.72	67.24	69.39	1782.3	95.33	64.61	1798.7	67.75	47.79	112.40	42.58
NS	192	4.60	2.45	2.81	2.04	45.63	38.00	1774.5	81.67	37.45	1830.8	37.63	14.49	51.94	27.05

The N% in the shoot and fruit increased with increasing the rate of N. The NS treatment increased the n% in the earlier growth stage more and as high as the fertigation treatments. During the later stage however, the N% by NS become lower that that by fertigation treatments but remain lower than the N0 treatment. The PUE and NUE were also measured by the difference method for the shoot and fruits during the growing season (Table 7). Their values are higher than that determined by the 15N method. The addition of N had a positive and synergistic effect on soil P and applied P through enhancing PUE and P% in the shoot and fruit.

Water utilization

The total water consumption was 80.1, 95.1, 96.2, 118.0 and 85.6 mm for N0, N1, N2, N3 and Ns treatments, respectively (Figure 11). Monthly water consumption was the minimum (7.2 mm) in July for N0 treatment and the maximum (50.2 mm) in Jun for N3 treatment (Figure 12). The value for the mean treatments were 11.7, 36.5, 38.3 and 8.3 mm for April, May Jun and July respectively (Figure 13). This indicate that the water consumption increased in Jun and then declined in July and that the increased was due to increased plant growth.

The application water use efficiency of fruit yield at different treatments, it was 5.3, 6.4, 6.9, 6.6,and 6.0 kg/m^3 for N0, N1, N2, N3 and Ns respectively (Figure 14). Consumption water use efficiency was 12.3, 17.8, 18.5, 12.7 and 16.7 kg/m^3 for N0, N1, N2, N3, and Ns respectively. Consumption water use efficiency for different treatments during the harvest (12-18 Jun) ranged from 4.7 to 4.2 kg/m^3 in the first week for N0 and N3 then increased to 45.5 kg/m^3 for N2 treatment. Then decreased at the end of the season to reach 5.2 kg/m^3 (Figure 15).

Squash crop coefficient was 0.24, 0.59, 0.7195, and 0.58 at the initial, developmental, mid seasonal and maturity stages respectively. The highest crop coefficient (KC) was observed for the N3 and the lowest for the N0 treatments (Figure 16 and Figure 17).

Water extraction from different soil depths was the highest (greater than 70%) at the top 30 cm of soil depth (Figure 18). On the other hand, the percentage of water extraction from the lower depth 75-90 cm was not exceeding 2%. Water extraction from different depths were 70.3%, 15.7%, 8.5%, 4% and 1.6% from 0.0-30, 30-45, 45-60, 60-75, and 75-90 cm respectively.

The amount of water absorption from the upper 30 cm soil depth was 88.2, 100.3, 92.5, 100 and 93.9 mm for N0, N1, N2, N3, and N0 treatment respectively. Water extraction from different depths were 237.5, 45.18, 27.44, 13.68 and 7.6 mm of water from 0.0-30, 30-45, 45-60 60-75, and 75-90 cm respectively. According to these results, most of plant roots were concentrated at the upper 30 cm of soil depth.

Table 7 P and N utilization by squash during the growing season of 2000.

Treatments		%P	%N	DW t ha^{-1}	P-up kg ha^{-1}	N-up kg ha^{-1}	PUE	NUE	PUE By N
Code	kg N ha^{-1}	Shoot at start of flowering							
N0	0.00	0.24	3.16	0.52	1.27	16.50	2.20	-	-
N1	91.00	0.29	3.45	0.67	1.96	23.22	3.40	7.39	2.08
N2	182.00	0.34	3.73	0.72	2.47	26.97	4.28	5.75	3.61
N3	264.00	0.31	3.67	0.86	2.65	31.67	4.60	5.75	4.16
NS	192.00	0.35	3.66	0.72	2.50	26.46	4.34	5.19	3.72
		Shoot at mid fruiting period							
N0	0.00	0.19	2.14	1.01	1.88	21.68	3.27	-	-
N1	91.00	0.20	2.68	1.62	3.20	43.47	5.55	23.95	3.95
N2	182.00	0.20	2.92	1.67	3.26	48.79	5.66	14.90	4.14
N3	264.00	0.19	3.14	1.92	3.59	60.23	6.23	14.60	5.13
NS	192.00	0.24	2.71	1.77	4.26	47.89	7.39	13.65	7.16
		Fruit at mid fruiting period							
N0	0.00	0.38	3.87	0.82	3.10	31.73	5.38	-	-
N1	91.00	0.39	4.32	1.33	5.17	57.46	8.98	28.27	6.25
N2	182.00	0.42	4.74	1.33	5.52	63.04	9.58	17.20	7.29
N3	264.00	0.39	4.66	1.20	4.73	55.92	8.21	9.16	4.91
NS	192.00	0.38	3.86	1.09	4.12	42.07	7.15	5.39	3.08
		Shoot at last harvest							
N0	0.00	0.20	1.87	0.94	1.91	17.50	3.32	-	-
N1	91.00	0.20	2.64	1.64	3.26	43.22	5.66	28.26	4.06
N2	182.00	0.19	2.63	1.70	3.17	44.63	5.51	14.91	3.81
N3	264.00	0.18	2.94	1.98	3.64	58.18	6.32	15.41	5.22
NS	192.00	0.19	1.88	1.56	2.99	29.38	5.18	6.19	3.24
		Fruit at last harvest							
N0	0.00	0.36	3.11	1.22	4.44	37.94	7.71	-	-
N1	91.00	0.38	3.45	2.03	7.75	70.04	13.46	35.27	9.99
N2	182.00	0.38	3.84	2.13	8.03	81.79	13.94	24.09	10.82
N3	264.00	0.39	3.87	1.81	6.99	70.05	12.13	12.16	7.67
NS	192.00	0.39	3.23	1.71	6.74	55.23	11.70	9.01	6.92

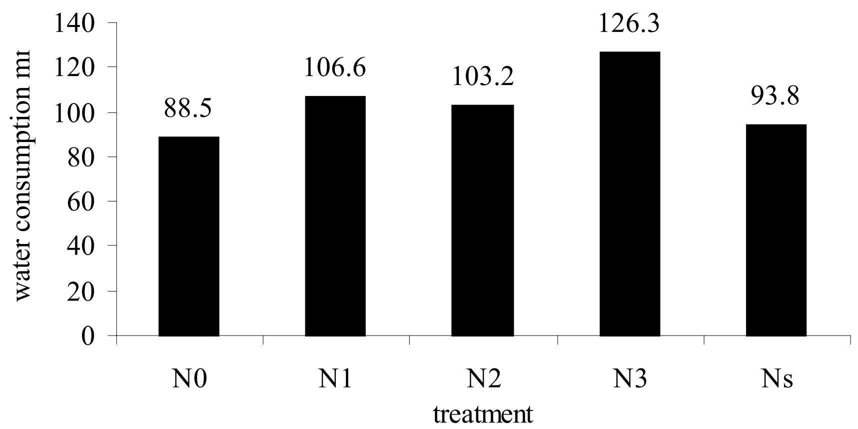

Figure 11 Seasonal water consumption, 2000.

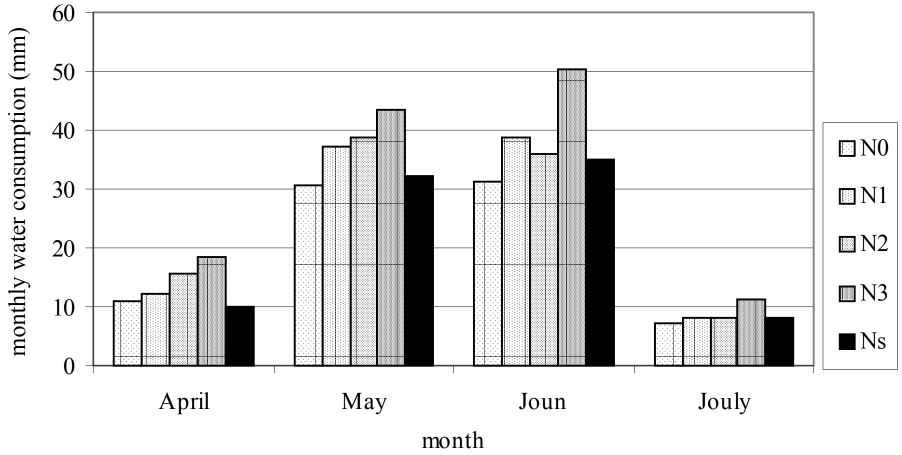

Figure 12 Water consumption, 2000.

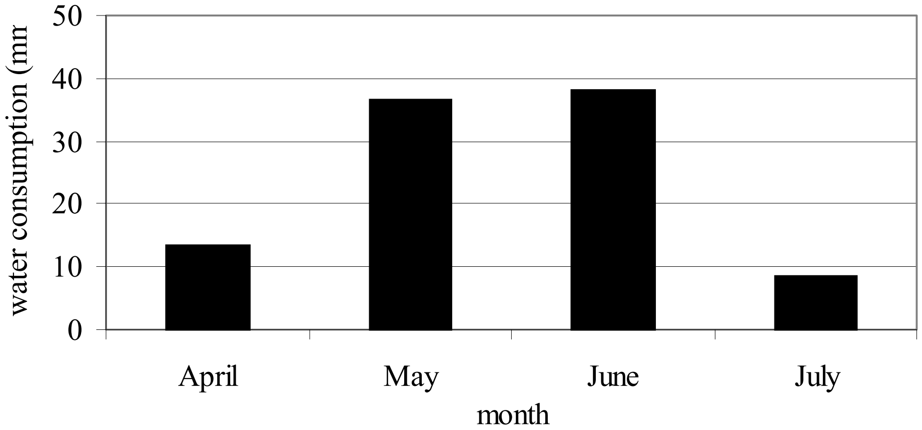

Figure 13 Water consumption, 2000.

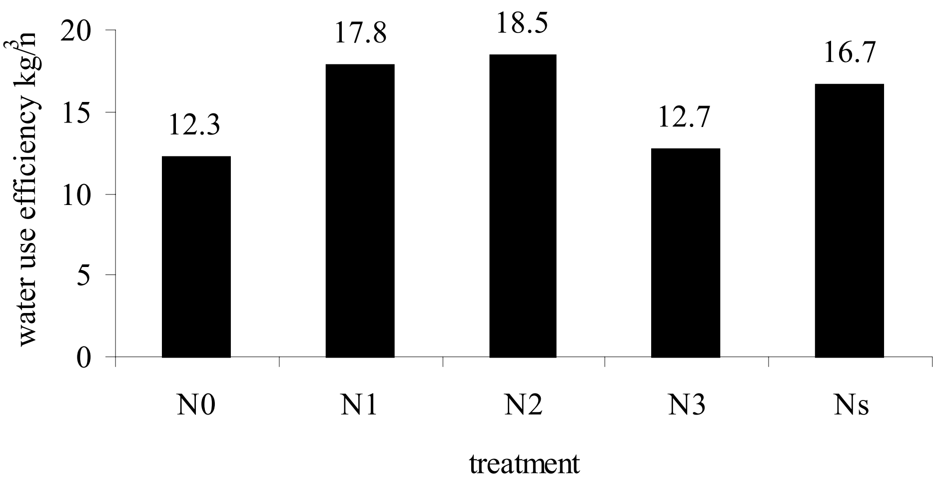

Figure 14 WUE, 2000.

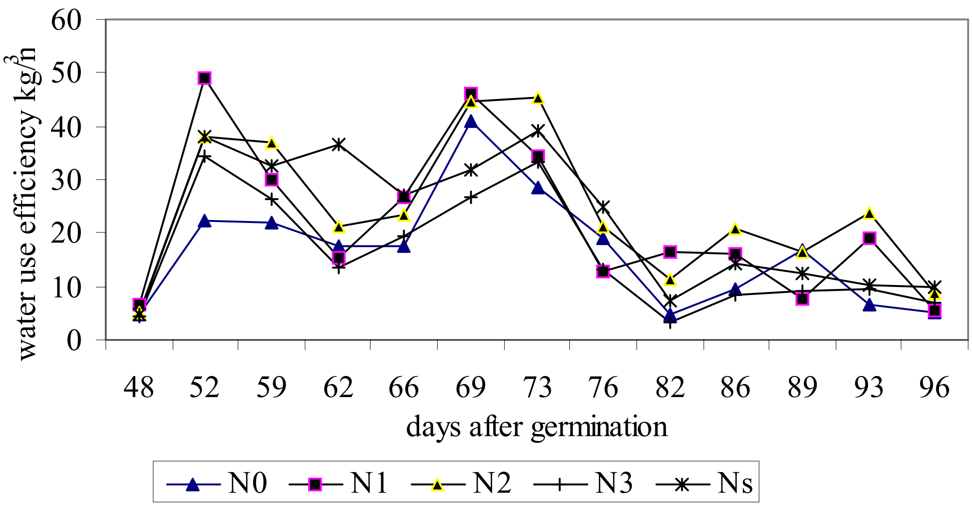

Figure 15 WUE, 2000.

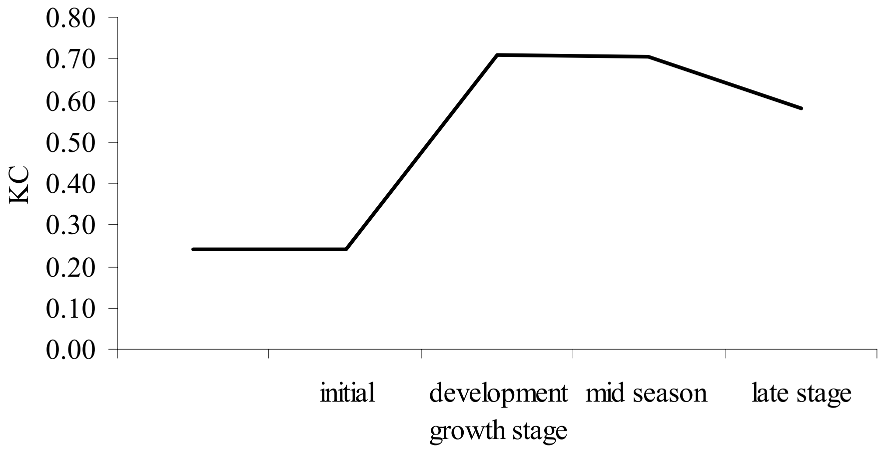

Figure 16 KC, 2000.

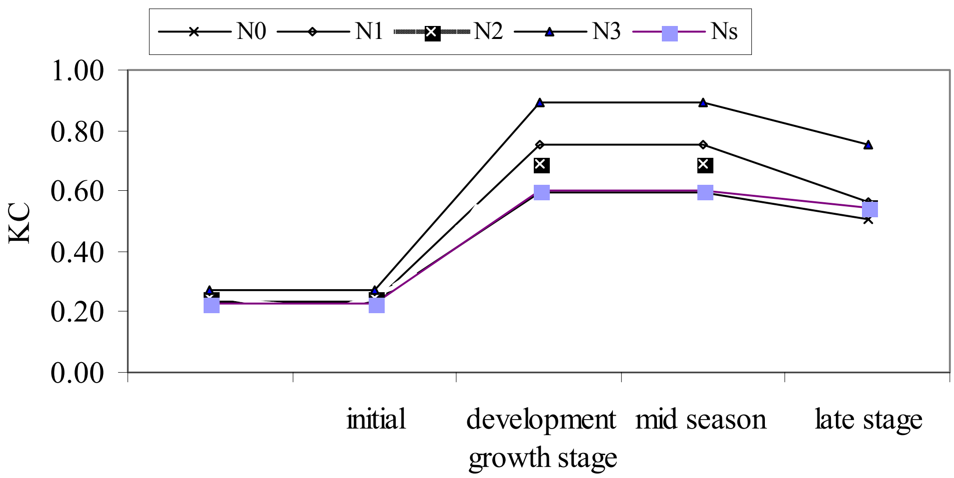

Figure 17 KC, 2000.

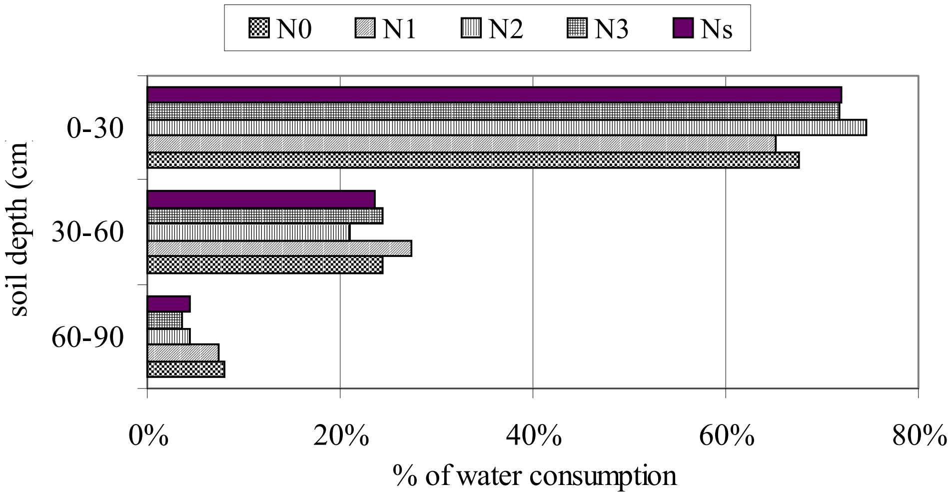

Figure 18 Water consumption, 2000.

Soil properties

At the end of the first and second growing seasons the soil pH and soil organic matter were not affected by the treatments (Table 8). Soil salinity was higher with N application especially at the top 15 cm of the soil layer and then decreased with soil depth. Soil P accumulated in the soil due to the phosphoric acid application to all experimental plots. The accumulation was higher at the top 15 cm and was the highest for the NO followed by NS treatments compared to other fertigation treatments.

Table 8 Soil properties at the end of the first year experiment.

Trts	Soil depth	pH	EC	Olsen-P	OM
	cm	-	dSm^{-1}	mg kg^{-1}	%
N0	00 - 15	7.98	0.45	38.04	0.96
N0	15 - 30	7.94	0.39	8.38	0.58
N0	30 - 60	8.06	0.38	9.55	0.49
N1	00 - 15	7.70	0.73	24.07	1.01
N1	15 - 30	7.80	0.51	5.44	0.72
N1	30 - 60	7.80	0.43	3.11	0.54
N2	00 - 15	7.81	0.77	21.41	1.05
N2	15 - 30	7.92	0.52	3.98	0.61
N2	30 - 60	7.71	0.54	3.65	0.45
N3	00 - 15	7.67	1.01	21.14	1.11
N3	15 - 30	7.81	0.68	5.27	0.68
N3	30 - 60	7.84	0.72	5.25	0.43
NS	00 - 15	8.01	0.72	23.35	1.12
NS	15 - 30	7.96	0.51	6.71	0.57
NS	30 - 60	7.81	0.52	2.45	0.45

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