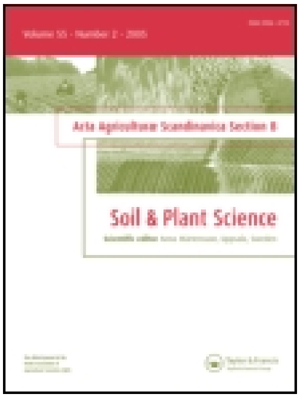

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Yield responses of cauliflower (*Brassica oleracea* L. var. Botrytis) to different water and nitrogen levels in a Mediterranean coastal area

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Abstract

Global warming along with the increasing population and fresh water shortages necessitates a specific fertilization programme under water-scarce conditions. This study was conducted to investigate the effects of different irrigation and nitrogen levels on yield, growth components and water use characteristics of cauliflower (*Brassica oleracea* L. var. Botrytis cv. Tetris-F_1) cultivated in a field for three consecutive years from 2005 to 2007 in the Eastern Mediterranean region of Turkey. Four irrigation (Kcp) levels with a drip irrigation system based on adjustment coefficients (0, 0.75, 1.0 and 1.25) of pan evaporation were used. Nitrogen (N) treatments were consisted of four different nitrogen rates (0, 75, 150 and 225 kg N ha^{-1}). The following yield and quality parameters were determined: curd weight, curd diameters, number of leaves per crop, above ground biomass (AGB) and curd/AGB ratio. Fertilizer use efficiency (FUE) and leaf mineral contents were also determined to clarify the productivity of N treatments. According to the results; the amount of irrigation water and/or total received water affects the plant water consumption, consequently, crop yield in a field grown cauliflower. The highest yield was obtained in $Kcp_{1.0}$ irrigation level which represents full irrigation treatment. The excess water applications had negative effect on yield and AGB of cauliflower. Highest yield was obtained at 225 kg N ha^{-1}.

The water use efficiency and irrigation water use efficiency values increased with decreasing irrigation rate. However, lower Kcp coefficients resulted in lower total yield. The FUE in irrigation treatments showed linear increases from non irrigation to full irrigation plots. However, excessive irrigation caused a decrease in FUE. It can be recommended that the $Kcp_{1.0}$ crop-pan coefficient with 225 kg ha^{-1} nitrogen application can be used to achieve the highest yield for field grown cauliflower in the Eastern Mediterranean coastal region of Turkey.

Keywords: *Drip irrigation, evapotranspiration, fertigation, fertilizer use efficiency, water use efficiency.*

Introduction

It is becoming more important to raise crop productivity in order to meet food demands of the increasing population of the world (Yildirim & Guvenc, 2005). Total production of cauliflower in Turkey was 150, 843 tons in 2008 (Anonymous, 2009). The production of fresh vegetables usually requires the application of considerable amounts of irrigation water and fertilizer nitrogen (Yu et al., 2006). Drip irrigation allows great flexibility in both water and N management (Thompson et al., 2000a). Efficient use of both fertilizers and water are critical to sustainable agricultural production. In fertigation, nutrients are applied through emitters directly into the root zone and consequently fertilizer-use efficiency (FUE) can be improved in comparison to conventional methods of fertilizer application (Hebbar et al., 2004). Cole crops grow in a wide variety of soil types, but their shallow root system – 45 to 60 cm – requires high levels of fertility as well as adequate water in the root zone (Marr, 1994). High rates of water and N requirements in relation to rapid rates of nitrification in thermic and hyperthermic soils, can contribute to increased production costs and losses of water and N. Therefore, accurate guidelines for water and N management in drip-irrigation of cauliflower cultivation are needed (Thompson et al., 2000b).

Although vegetable lands receive large amounts of water from rainfall under a typical Mediterranean climate, this water often comes at times when there are no crops in the field. Therefore, irrigation is required during most seasons for successful vegetable production (Hochmuth, 2000). Irrigation management is an important issue which not only has a direct influence on quality but also affects indirectly the yield response of crops to fertilizer applications (Kirda et al., 2003). Thus, the relationship between

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crop production and the amount of irrigation water applied to the crop is important to agronomists, engineers, economists and water resource planners (Gutezeit, 2003). Water supply is a major constraint to crop production in the Mediterranean region of Turkey. The precise determination of irrigation water requirement is an important prerequisite for high irrigation water use efficiency (Kochler et al., 2007).

In irrigated agriculture, water management has a pronounced influence on N management, and an understanding of this interaction is needed for selecting N management practices optimizing crop yield and minimizing N losses (Sanchez et al., 1996). The individual or collective effects of water and N management on yields have been reported for several drip-irrigated vegetable crops (Kanber et al., 1999; Kirda et al., 2003; Cetin et al., 2004; Ertek et al., 2004; Sezen et al., 2006) in the region. The water and N-response characteristics of drip-irrigated cauliflower under East Mediterranean conditions have not previously been reported.

In this study, we conducted a 3-year field experiment with cauliflower to determine the effects of water and N management on yields, growth components and water use characteristics of the crop under conditions of the Eastern Mediterranean Region of Turkey.

Materials and methods

Site description

Cauliflower (*Brassica olearacea* L. botrytis cv. Tetris F_1) was cultivated during the 2005 through 2007 autumn growing seasons. The experiment was carried out in a farmer's field located in Samandag, Hatay, Turkey, at latitude 36° 06' N and longitude 35° 57' E, and 58 m above sea level. Transplanting and harvesting dates of cauliflower according to weather conditions are shown in Table I.

Samandag has a typical Mediterranean climate with hot-dry summers and mild-rainy winters. The long-term mean, maximum and minimum temperatures during the growing periods (August–November) are 22.9, 41.0 and 0.0°C, respectively. The mean precipitation is 268.4 mm. Some climatic

Table I. Transplanting and harvesting dates (day of the year) and growing period (days) of cauliflower.

Years	Transplantation	Harvest	Growing period
2005	217 (August 5)	334 (Nov. 30)	118
2006	214 (August 2)	331 (Nov. 27)	118
2007	212 (July 31)	332 (Nov. 28)	121
Mean	214	332	119

Table II. Some climatic data of the study area during the experiment.

	Temperature (°C)												Mean air humidity (%)				Wind speed (m s^{-1})			
	Maximum				Minimum				Average											
Months	2005	2006	2007	LT	2005	2006	2007	LT	2005	2006	2007	LT	2005	2006	2007	LT	2005	2006	2007	LT
August	30.0	30.4	30.8	40.4	26.5	26.7	26.9	17.0	27.9	28.2	28.5	27.8	81	77	86	80	4.9	5.6	6.1	5.2
September	29.1	30.4	30.3	41.0	22.7	23.4	24.4	13.0	26.1	26.6	27.0	26.2	73	70	81	75	3.2	4.0	4.2	3.9
October	25.8	26.0	28.7	37.2	15.9	18.3	20.0	6.8	20.4	21.7	24.0	21.8	65	73	66	69	3.1	3.5	3.7	3.1
November	18.9	20.1	20.8	30.0	11.0	10.3	13.3	0.0	14.7	14.7	16.7	15.8	64	59	73	66	4.1	4.5	5.0	4.0
Seasonal	30.0	30.4	30.8	41.0	11.0	10.3	13.3	0.0	22.3	22.8	24.1	22.9	70	70	76	73	3.8	4.4	4.8	4.1

LT: Long-term (from 1975 to 2007).

data of the experimental area during the experimental periods are given in Table II.

Soil, water and plant analyses

The soil samples were air-dried, gently crushed and passed through a 2 mm sieve in order to prepare for analyses. Particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). Soil chemical properties were determined following standard procedures (Sparks, 1996): both pH and electrical conductivity in saturation paste, organic matter by $K_2Cr_2O_7$ oxidation, $CaCO_3$ equivalent of the soils was determined with a Scheibler calcimeter (Allison & Moodie, 1965), available P by extraction with 0.5 M $NaHCO_3$ at pH 8.5 (1 g: 20 mL soil: extractant), available K by extraction with1 M CH_3COONH_4 at pH 7.0, CEC by saturating the exchange sites with 1 M CH_3COONa at pH 8.2 then replacing the Na with 1 M CH_3COONH_4 at pH 7.0, available micronutrients extracted with DTPA. Experimental soils had 0.53% total organic matter content, 21% $CaCO_3$, 0.18% total N, 12.35 mg kg^{-1} available P_2O_5, 301.27 mg kg^{-1} exchangeable K_2O, 9.15 mg kg^{-1} Fe, 1.53 mg kg^{-1} Zn, 6.4 mg kg^{-1} Mn, 1.86 mg kg^{-1} Cu before the initiation of the experiment. Some other properties of the experimental soils related to irrigation are shown in Table III.

Ground water was also characterized as very deep (deeper than 120 cm) in the profile. Irrigation water used in the study was obtained from a deep well because there is no available surface fresh water source in the region. The irrigation water sampled from the well at the beginning of the study was analyzed and classified using standard procedures (Anonymous, 1954). The results showed that the water is C_2S_1 class and has no serious harmful effect on plant growth. Some of the water quality parameters were: EC 0.53 dS m^{-1}, pH 7.8, TDS 0.47 g L^{-1}, SAR 0.31, Na 0.52 me L^{-1}, K 0.03 me L^{-1}, Ca + Mg 5.52 me L^{-1}, CO_3 0.25 me L^{-1}, HCO_3 3.17 me L^{-1}, Cl 1.90 me L^{-1} and SO_4 0.76 me L^{-1}.

Leaf sampling was done at destructive harvest from young leaves, to determine the mineral contents in cauliflower leaves. Samples were dried at 70 °C until constant weight and homogenized by reducing the particle size < 0.5 mm. Powdered samples were digested with $HNO_3/HClO_4$ mixture (4:1 v/v) (Kacar, 1972). Semi-micro Kjeldahl method was used to determine N content of samples (Lees, 1971). Phosphorus content was spectrophotometrically determined by Barton reagent (Barton, 1948). The concentrations of Ca, Mg, K, Na, Fe, Cu, Mn and Zn in digest were determined by means of an inductively coupled

Table III. Some physical and chemical characteristics of experimental soil.

Soil depth (cm)	Particle size distribution (g kg^{-1})			Texture class	$CaCO_3$ (g kg^{-1})	Saturation (%)	FC (g g^{-1})	WP (g g^{-1})	Bulk density (g cm^{-3})	Salt (%)	pH	CEC cmol kg^{-1}
	Clay	Sand	Loam									
0–20	493.1	207.8	299.0	Clay	548	60.6	42	28	1.24	0.03	7.6	21.7
20–40	483.5	232.0	284.5	Clay	533	58.4	41	27	1.25	0.03	7.6	22.4
40–60	486.6	247.9	265.4	Clay	543	59.6	41	27	1.25	0.03	7.6	23.8

FC: field capacity; WP: wilting point; CEC: cation exchange capacity.

Table IV. Irrigation water (*I*, mm), crop water use (*Et*, mm), water use efficiency (WUE, kg m^{-3}) and irrigation water use efficiency (IWUE, kg m^{-3}) of cauliflower under four different crop–pan coefficients (Kcp) and some other parameters related to irrigation during the study.

Irrigation treatments	2005				2006				2007				Mean			
	I	Et	WUE	IWUE	I	Et	WUE	IWUE	I	Et	WUE	IWUE	I	Et	WUE	IWUE
$Kcp_{0.}$	85	189	7.49	16.7	85	253	6.08	18.1	127	197	5.45	8.46	99	213	6.3	14.4
$Kcp_{0.75}$	202	417	7.28	15.0	159	439	5.87	16.2	381	511	4.93	6.61	247	455	6.0	12.6
$Kcp_{1.0}$	270	491	6.65	12.1	212	522	5.67	14.0	507	694	4.88	6.67	329	569	5.7	10.9
$Kcp_{1.25}$	337	537	6.19	9.87	265	565	4.82	10.3	634	814	3.74	4.8	412	638	4.9	8.3
Epan (mm)			532				530				694				585	
Effective rain (mm)			263				318				187				256	
Number of irrigation applications			8				5				14				9	

plasma atomic emission spectrometer (ICP-AES, Varian, Liberty Series II).

Experimental design

The experimental design was split-plots with three replications. The main plots were the rates of nitrogen (N) fertilizer and the sub-plots were irrigation levels (Kcp) derived from cumulative evaporation in a Class-A pan between two irrigation events. In the experiment, four different irrigation levels and four nitrogen rates were tested as treatments. The irrigation levels were full irrigation ($Kcp_{1.0}$), 75% of full irrigation ($Kcp_{0.75}$; 25% deficit), 125% of full irrigation ($Kcp_{1.25}$; 25% excess) and control (Kcp_0) treatments. The N treatments were 75 (N_{75}), 150 (N_{150}) and 225 (N_{225}) kg N ha^{-1} in addition to soil mineral nitrogen. A control treatment was also included with no fertilizer N. Ammonium nitrate (33.5% N) was used as the N source. The same amounts of phosphate (monopotassium phosphate, 52% P_2O_5 and 34% K_2O) and potassium (potassium sulfate, 51% K_2O) fertilizers were applied to the plots which were 120 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. The fertilizers were applied through drip irrigation in four split-applications. In order to minimize available N in the root zone and reduce field variability, plant residues were removed from the field before and after each growing period and the field was left vacant until the subsequent growing year.

The sub-plots were 22.2 m long and 1.8 m wide and spaced 0.5 m apart. Each plot had three rows of plants. The plants were transplanted in the field at a spacing of 0.6 m × 0.6 m. Pest and disease control were done according to guidelines for standard cauliflower production.

The drip lateral lines were installed on the surface with one drip line for each crop rows after transplanting of cauliflower seedling. The drip irrigation laterals were 16 mm in diameter. The drippers were inline type and placed 0.20 m apart from each other and had 2.0 L h^{-1} flow rate at 100 kPa pressure. The irrigation system has a classic control unit consisting of a pump, fertilizer tank, hydro-cyclone and disc filters, control valves, pressure gauges and a flow meter. After transplanting the plants, all plots were equally irrigated for the first 12–15 days to provide a good stand establishment. In this period, a total of 85 mm irrigation water was applied with 2–3 day intervals. When the readings of a tensiometer placed in 30 cm soil depth (Thompson et al., 2000b) on the full irrigation ($Kcp_{1.0}$) plot approached 25 kPa, the treatment irrigations were then started.

The amount of irrigation water was calculated using Equation (1):

$$I = A\ Epan\ Kcp \quad (1)$$

Where, I is the amount of irrigation water (L), A is the plot area (m^2), *Epan* is the amount of cumulative evaporation during an irrigation interval (mm), *Kcp* is the crop-pan coefficient. Class-A pan is located at the centre of the field. Daily readings of the pan evaporation were made in the mornings (08 ~09 am) during the study. Average rooting depth of cauliflower is about 0.60 metre (Walker, 1989). Therefore, soil water content was measured gravimetrically at 0.60 m depth from the middle row of every plot at each irrigation event one day before irrigation. Crop water consumption (evapotranspiration, Et) under varying watering regimes was calculated using the soil water balance equation (James, 1988):

$$Et = I + P \pm \Delta SW - Dp - Rf \quad (2)$$

Where, *Et* is the evapotranspiration or crop water consumption (mm), I is the irrigation water (mm), P is the precipitation (mm), ΔSW is the change in the soil water storage (mm) in 60 cm soil profile, *Dp* is the deep percolation (mm), and *Rf* is the amount of runoff (mm). Precipitation values were obtained from a nearby meteorological station. Since drip irrigation was used in the study, runoff was assumed as zero. Deep percolation was calculated from the difference between the field capacity moisture level and total soil moisture level at 0.60 m soil depth in the observed period (Kashyap & Panda, 2003).

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated as marketable cauliflower curd yield divided by seasonal evapotranspiration and seasonal irrigation water applied, respectively (Howell et al., 1990). Fertilizer-use efficiency (FUE) was worked out as a factor of total economic yield from all harvests by the quantity of fertilizer applied and expressed as% (Hebbar et al., 2004).

Plants were harvested at 120 days after transplantation. All measurements were taken from the plants in the middle rows of the plots. Crops were hand-harvested 1 cm above the soil surface and weighted for above-ground biomass (AGB). The heads were then trimmed by removing the leaves (Pascale et al., 2005). Then weights of marketable heads were determined. At the beginning of harvest, five plants per plot were randomly sampled to measure leaf number, curd diameter, mean curd weight per plant, total curd yield, AGB and curd/AGB ratio according to standard procedures.

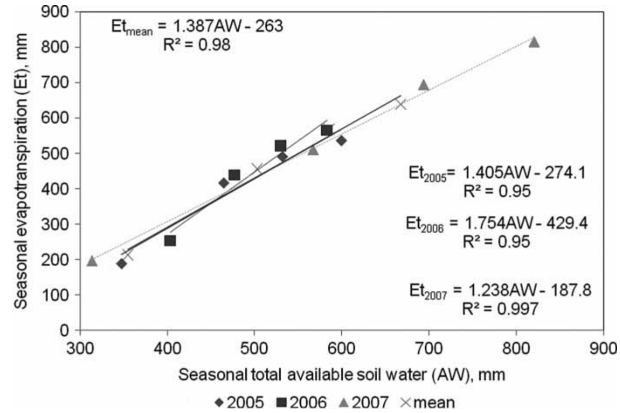

Figure 1. Mean and yearly relationships between seasonal total available water (irrigation + rainfall) in soil and seasonal evapotranspiration in three consecutive experimental periods.

Data analysis

Data obtained in this study were subjected to analysis of variance (ANOVA) with the MSTAT-C software (Michigan State University) and the treatment means were compared by Duncan's multiple range test at $p < 0.05$.

Results and discussion

Irrigation and crop evapotranspiration (Et)

Irrigation regimes in the experiment were changed by rainfall regime in each year. Total rainfalls during the experiment were 403, 489 and 187 mm in 2005, 2006 and 2007, respectively. The calculated amounts of percolation were 140 and 171 mm in 2005 and 2006 years, respectively. In 2007, rainfall intensity did not exceed field capacity. Therefore, there was not any percolation in this year. The irrigation amount varied with irrigation (Kcp) levels as expected. Amounts of total irrigation water during

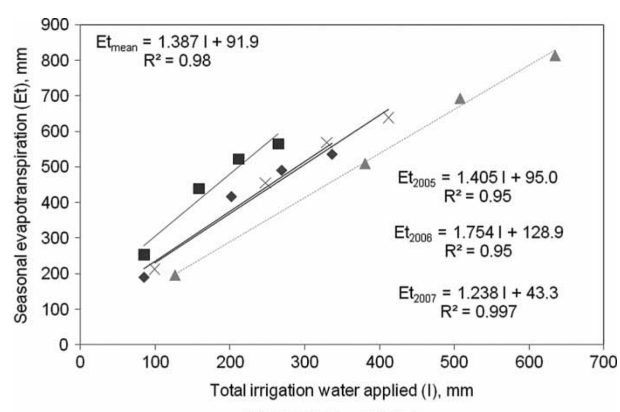

Figure 2. Mean and yearly relationships between total irrigation water applied to cauliflower and seasonal evapotranspiration in three consecutive experimental periods.

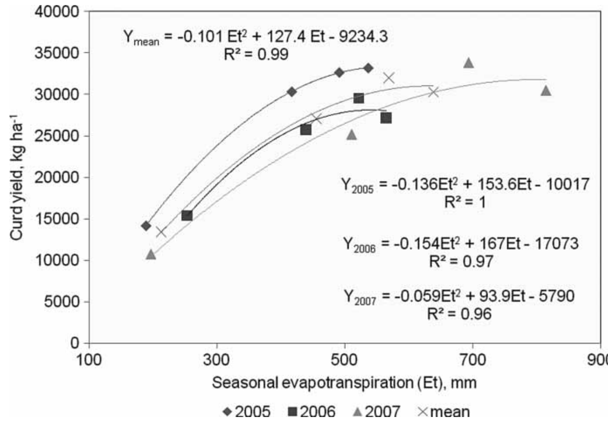

Figure 3. Mean and yearly relationships between cauliflower curd yield and seasonal evapotranspiration in three consecutive experimental periods.

the growing period changed from 85 to 337 mm in 2005, from 85 to 265 in 2006 and from 127 to 634 mm in 2007 (Table IV). Irrigation intervals, and accordingly the number of irrigation events, varied from year to year depending on climatic parameters, especially frequency and amounts of rainfall. Irrigation intervals varied from 5 to 15 days depending on rainfall event during the experiment. Number of irrigation applications was 8, 5 and 14 in the first, second and third experimental years, respectively.

Crop evapotranspiration (*Et*) changed with the amounts of irrigation water and total available soil water (irrigation plus rainfall, AW) in each experimental year. Evapotranspiration of cauliflower varied from a minimum of 189 mm in the first year to a maximum of 814 mm in third year. Evapotranspiration in first and second experimental years were highly similar in each irrigation treatment. However, due to excessive seasonal evaporation, irrigation water plus rainfall amount in the third experimental year was greater than the other seasons. This extremity caused the highest reference crop evapotranspiration (814 mm) in $Kcp_{1.25}$ treatment plots which had the maximum number of leaves in this season. The larger cauliflower leaves led to the faster rate of moisture loss and more frequent irrigation is often needed to prevent water stress and yield losses (Anonymous, 1994). The *Et* values changed from 213 mm in Kcp_0 to 638 mm in $Kcp_{1.25}$ treatments with respect to overall mean of the three experimental years. There was a significant linear relationship between seasonal total available soil water and seasonal evapotranspiration in each experimental year (Figure 1). Similarly, there was also a significant linear relationship between total irrigation water applied and seasonal evapotranspiration that occurred (Figure 2). Prabhakar and Srinivas (1995) reported that an increase in irrigation from 25 to 100% of *Epan* linearly increased curd yield (from 8.06 to 16.22 t ha^{-1}) and crop *Et* (from 238 to 541 mm). In our experiment, there was a significant second degree polynomial relationship between the seasonal crop evapotranspiration and cauliflower curd yields (Figure 3) and total irrigation water applied and cauliflower curd yields (Figure 4) in each experimental year. Similar results were also reported by Sarkar et al. (2009) that higher amounts and frequencies of irrigation had reduced the curd yield of cauliflower.

Water use characteristics

The effects of irrigation treatments on Et, WUE and IWUE are given in Table IV. The WUE values ranged from a minimum of 3.74 kg m^{-3} in the $Kcp_{1.25}$ in 2007 to a maximum of 7.49 kg m^{-3} in the Kcp_0 in 2005. The WUEs in the experiment were increased by decreasing amounts of total irrigation water. Westarp et al. (2004) declared that the overall efficiency of water use for cauliflower under deficit (50%) irrigation regime was higher than under full irrigation regime. With respect to mean WUE values of three experimental years, the highest WUE value was 6.3 kg m^{-3} for the lowest amount of water received (Kcp_0) plots, whereas the lowest WUE value was 4.9 kg m^{-3} for the highest amount of water received ($Kcp_{1.25}$) plots. The same trends were determined in three consecutive experimental years. Similar results were reported for different crops (Faberio et al., 2001; Ertek et al., 2004). Irrigation water use efficiency (IWUE) values were higher than the values of the WUE. The IWUE values had similar behaviour with the WUE values. In general, the higher amounts of irrigation water led to lower IWUE values in the experiment. Minimum IWUE was found in 4.8 kg m^{-3} in the $Kcp_{1.25}$ treatment plots in the third year and maximum

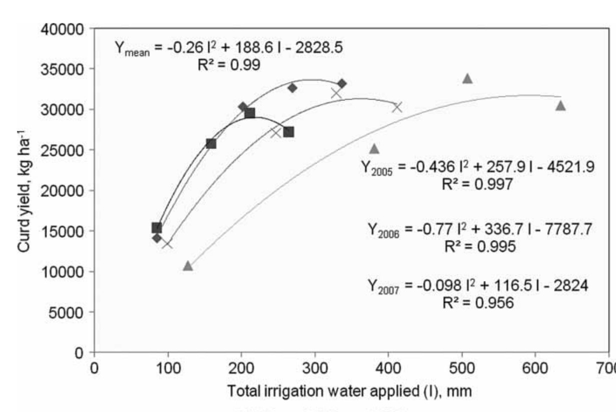

Figure 4. Mean and yearly relationship between cauliflower curd yield and total irrigation water applied in three consecutive experimental periods.

IWUE was found in 18.1 kg m^{-3} in the Kcp$_0$ in the second year. With respect to yearly mean, IWUE values changed from 8.3 kg m^{-3} in the Kcp$_{1.25}$ to 14.4 kg m^{-3} in the Kcp$_0$ treatment plots.

Yield and growth components

Different levels of N and water deficits caused variations in crop yield and considered growth components. Variance analyses were performed to determine the effects of different irrigation level and nitrogen rates on cauliflower yield and growth components (Table V). Since the differences of yields among experimental years and replications were not found to be statistically significant, combined variance analyses were done for all investigated parameters in the experiment. Analysis of variance revealed significant differences among the nitrogen rates and irrigation levels for curd weight and diameter, yield, AGB, number of leaves per crop and curd weight/AGB ratio.

The multiple range tests of Duncan showed that curd yield, curd diameter and curd/AGB ratio was strongly affected by nitrogen treatments. Lowest curd yield was determined in N$_0$ treatment. Similar results were reported by Cai-yan et al. (2008). Increased nitrogen rates caused an increase in curd yield, curd diameter and curd/AGB ratio in our study. Predicted maximum curd yields (33.9 Mg ha^{-1}) and curd/AGB ratio (33.7%) occurred at N rates of 225 kg ha^{-1} (Table VI). Mehdi et al. (2003) reported that increasing N from 0 to 225 kg ha^{-1} significantly increased the curd depth and curd weight. Boogaard and Thorup-Kristensen (1997) concluded that total nitrogen supply can be reduced to approximately 250 kg ha^{-1} without negative effects on yield. Furthermore, they also declared that the yield and quality of cauliflower were not affected when total nitrogen supply, i.e. fertilizer plus soil mineral nitrogen, was above 250 kg ha^{-1}. Similarly, Everaarts and De Moel (1995a) found an optimum rate of 224 kg ha^{-1} minus mineral soil nitrogen to a depth of 0.6 m.

The AGB production was slightly changed with the increased N rates except for no nitrogen treatment. In general, the plant AGB was higher in the higher N supply treatments and the lowest AGB (2.58 kg plant^{-1}) was found in N$_0$ treatment. These findings implied that the soil N did play a key role in the accumulation of plant biomass because of the increased requirements of nutrients for plant growth as reported by Sun et al. (2009). Bjelic and Moravcevic (2005) pointed out that nitrogen application increased the yield of cauliflower fodder (stems and leaves), constituted 65–72% of the total plant biomass, on average by 26.20 Mg ha^{-1}. In

Table V. Variance analyses of cauliflower yield and growth components.

Source of variance	df	Curd weight, kg plant^{-1}	AGB, kg	No. of total leaf, no. plant^{-1}	Curd diameters, cm	Curd/AGB ratio	Yield, Mg ha^{-1}
Years (Y)	2	ns	**	**	*	ns	ns
Replication(R)	2	ns	ns	ns	ns	ns	ns
Nitrogen rates (N)	3	**	**	**	**	**	**
Y × N	6	ns	ns	*	ns	**	ns
Irrigation level (Kcp)	3	**	**	**	**	**	**
Y × Kcp	6	ns	ns	ns	**	ns	ns
N × Kcp	9	*	**	**	**	**	*
Y × N × Kcp	18	ns	**	**	**	ns	ns
CV (%)		25.65	14.29	11.34	10.49	21.27	25.63

*Significant at $p < 0.05$, **significant at $p < 0.01$, df: degrees of freedom, CV: coefficient of variation; AGB: above-ground biomass, ns: not significant.

Table VI. The Duncan's mean comparison of yield and growth components under different nitrogen rates and irrigation levels.

Treatments		Curd weight, kg plant^{-1}	AGB, kg plant^{-1}	No. of total leaf, no. plant^{-1}	Curd diameters, cm	Curd/AGB Ratio,%	Yield, Mg ha^{-1}
Years	2005	1.00	3.52a*	36.1b	16.0a	26.6	27.6
	2006	0.88	3.24b	36.9b	14.8b	26.0	24.5
	2007	0.90	3.06b	39.9a	15.2ab	28.2	25.1
	$LSD_{0.05}$	ns**	0.27	1.93	0.80	ns	ns
Nitrogen rates	N_0	0.32c	2.58b	34.39c	10.3c	11.7c	8.81c
	N_{75}	1.05b	3.48a	40.1a	16.3b	30.1b	29.1b
	N_{150}	1.12ab	3.43a	37.3b	17.3a	32.2ab	31.0ab
	N_{225}	1.22a	3.60a	38.8ab	17.4a	33.7a	33.9a
	$LSD_{0.05}$	0.13	0.31	2.23	0.92	2.37	3.59
Irrigation level	Kcp_0	0.49c	2.43c	35.1b	11.2c	19.1b	13.4c
	$Kcp_{0.75}$	0.98b	3.38b	38.7a	16.0b	28.4a	27.1b
	$Kcp_{1.0}$	1.16a	3.77a	37.4a	16.9a	29.5a	32.0a
	$Kcp_{1.25}$	1.09a	3.52b	39.3a	17.2a	30.7a	30.3a
	$LSD_{0.05}$	0.12	0.22	2.01	0.76	2.69	3.10

*Means followed by the same letter(s) in the same column are not significantly different at 0.05 level, **ns: non significant; AGB: above-ground biomass.

agreement with this report, we found that the fodder yield constituted 66.3–71.6% of the AGB in all treatment plots except for control (no N and no irrigation) plots. The effects of N rates on number of leaves was not clear. Although N rates had a statistically significant effect on number of leaves, there was a fluctuation among different N rates.

In view of the irrigation treatment, the average curd yield of cauliflower in three years was 25.7 Mg ha^{-1}. Similar yield results were reported by Yu et al. (2006). Irrigation treatments had significant effects on cauliflower curd yield. $Kcp_{1.0}$ irrigation treatments had the highest curd weight among all irrigation treatments. Thus, maximum cauliflower curd yield (32.0 Mg ha^{-1}) was obtained in $Kcp_{1.0}$ irrigation level which represents full irrigation treatment. There was considerable reduction in cauliflower curd yield and AGB from $Kcp_{1.0}$ to Kcp_0 deficit irrigation levels, particularly in Kcp_0 (Table VI). As reported earlier by Kaniszewski and Rumpel (1998), the lowest AGB and curd weight was obtained on the non-irrigated treatment. Westarp et al. (2004) reported that the crop residue (all leaf plus stem weight) was either significantly reduced or showed a trend towards lower production under the lower volumetric water content of deficit irrigation regime. Hence, they suggested that plants may preferentially partition resources to the cauliflower fruit, at the expense of leaves and green matter. The $Kcp_{1.25}$ irrigation treatment (25% excess) had a negative effect on curd yield and AGB. In this treatment, total curd yield decreased about 5.37% compared with the $Kcp_{1.0}$ irrigation treatment. The roots of cauliflower, like other vegetable plants, need free oxygen in order to breathe and to take up water (Anonymous, 1994). Therefore, this reduction may explained by poor soil aeration resulting from excessive irrigation and/or increased water percolation and leaching of nitrate and other mobile plant nutrients into the deeper soil horizons by excessive irrigation (Diez et al., 1997; Sarkar et al., 2009). Irrigation treatments had not clearly influenced number of leaves as N treatments in our study. Xiao and Subbarao (2000) declared that the number of cauliflower leaves and the dry weight of leaves and roots were not different among the three (deficit, moderate and excessive) irrigation regimes. ZhenXian and ShuHua (1995) declared that a close correlation was found between cauliflower curd weights and weight of other organs. Curd diameters of cauliflower increased with increasing irrigation water and N rates in our study. Moreover, significant correlations were found between curd weight and AGB ($R^2 = 0.77$**), curd weight and number of total leaf ($R^2 = 0.22$**) and, curd weight and curd diameter ($R^2 = 0.90$**).

Table VII. Interaction effects of different N rates and irrigation levels on yield and growth components.

Treatments		Curd weight, kg plant^{-1}	AGB, kg plant^{-1}	No. of total leaf, no. plant^{-1}	Curd diameters, cm	Curd/AGB ratio	Yield, Mg ha^{-1}
N_0	Kcp_0	0.11f	1.44h	21.7c	5.87e	7.50e	2.89f
	$Kcp_{0.75}$	0.25ef	2.84efg	38.4ab	10.3d	9.17e	6.96ef
	$Kcp_{1.0}$	0.37de	2.85efg	36.3b	11.0d	13.0de	10.4de
	$Kcp_{1.25}$	0.54cd	3.18cde	41.1ab	14.1c	17.3d	15.0cd
N_{75}	Kcp_0	0.51cd	3.08def	42.3a	11.5d	17.9d	14.3cd
	$Kcp_{0.75}$	1.15b	3.56bcd	40.4ab	16.6b	33.1ab	31.9b
	$Kcp_{1.0}$	1.38ab	3.70b	38.0ab	19.3a	37.3a	38.2ab
	$Kcp_{1.25}$	1.16b	3.60bc	39.7ab	17.7ab	32.1ab	32.0b
N_{150}	Kcp_0	0.62cd	2.63fg	36.4b	14.4c	23.7c	17.1c
	$Kcp_{0.75}$	1.20b	3.55bcd	38.4ab	18.1ab	34.2a	33.3b
	$Kcp_{1.0}$	1.37ab	3.86b	37.0b	18.6a	35.8a	38.0ab
	$Kcp_{1.25}$	1.29ab	3.67bc	37.2b	18.2ab	35.0a	35.8ab
N_{225}	Kcp_0	0.70c	2.56g	39.8ab	13.3c	27.4bc	19.4c
	$Kcp_{0.75}$	1.31ab	3.56bcd	37.7ab	18.8a	37.0a	36.2ab
	$Kcp_{1.0}$	1.50a	4.66a	38.3ab	18.7a	32.0ab	41.4a
	$Kcp_{1.25}$	1.39ab	3.62bc	39.3ab	18.7a	38.3a	38.4ab
$LSD_{0.05}$		0.22	0.44	4.01	1.51	5.38	6.19

*Means followed by the same letter(s) in the same column are not significantly different at 0.05 level; AGB: above-ground biomass.

Irrigation levels and N rates interactions had statistically ($p < 0.05$) significant effect on yield and growth components of cauliflower at $p < 0.01$ levels. Combined effects of irrigation regime and nitrogen applications on cauliflower yields are given in Figure 5. Maximum total curd yield (41.4 Mg ha^{-1}) was obtained at 225 kg N ha^{-1} (N_{225}) and full (569 mm) irrigation level ($Kcp_{1.0}$). Likewise, maximum AGB was also obtained in the same interaction (Table VII). Sanchez et al. (1996) reported that ranges of water and N required for maximum cauliflower yield were 470–730 mm and 295–369 kg N ha^{-1}, respectively. The generalized response equation in their study predicts 650 mm of water and N at 338 kg ha^{-1} to achieve a maximum yield of 24.8 Mg ha^{-1} in the low desert of the southwestern USA. In our $N_{225} \times Kcp_{1.25}$ interaction plots, total cauliflower yield decreased about 7.36% compared with the $N_{225} \times Kcp_{1.0}$ interaction plots, probably because of the effects of nutrient loss by leaching (Sanchez et al., 1996) and/or denitrification process as reported by Ryden and Lund (1980). Other investigated growth parameters of cauliflower did not show considerable responses to $N \times Kcp$ interactions.

Leaf mineral content

Leaf mineral contents were determined by using leaf samples taken from the destructive harvest (data are not given). Nitrogen treatments had a significant effect on leaf N, P, K, Ca, Mg, Na, Cu, Fe, Mn and Zn contents at $p < 0.01$ probability level. Irrigation treatments had also a statistically significant effect on leaf P, Ca, Mg, Na, Mn and

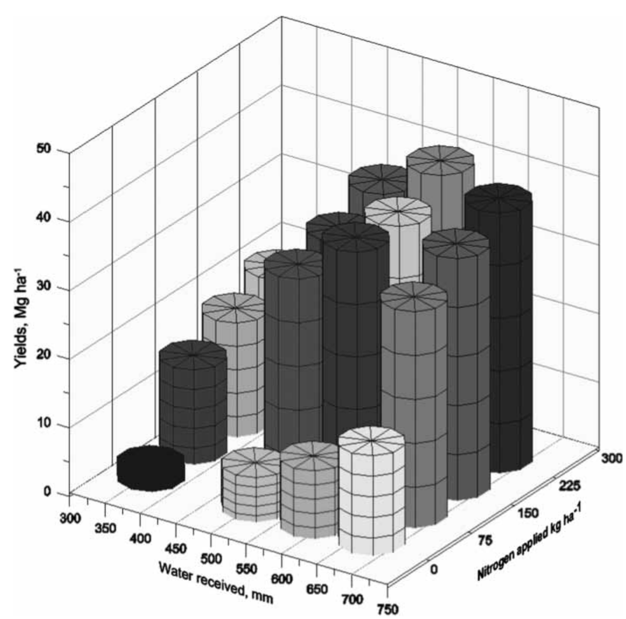

Figure 5. Combined effects of irrigation water applied and nitrogen rates on cauliflower curd yields.

Table VIII. Mean fertilizer use efficiency (FUE) for main and interaction plots.

Main factors				Interaction effects (N × Kcp)				
					FUE			
N Treatments	FUE[1]	Irrigation (Kcp) treatments	FUE		N_0	N_{75}	N_{150}	N_{225}
N_0	36.7c	Kcp_0	35.8c	Kcp_0	12.1	45.2	43.9	41.8
N_{75}	92.4a	$Kcp_{0.75}$	73.4b	$Kcp_{0.75}$	29.0	101	85.3	77.9
N_{150}	79.6ab	$Kcp_{1.0}$	87.8a	$Kcp_{1.0}$	43.2	121	97.5	89.1
N_{225}	72.8b	$Kcp_{1.25}$	84.6a	$Kcp_{1.25}$	62.6	102	91.7	82.5
$LSD_{0.05}$	17.8	$LSD_{0.05}$	10.0	$LSD_{0.05}$	ns			
F_{value}	19.2**	F_{value}	48.9**	F_{value}	2.07			

[1]kg yield kg^{-1} NPK; ns: non significant; ** significant at $p<0.01$.

Zn contents at $p<0.01$ probability level. Combined effect of N and Kcp treatment had also significant effect on investigated leaf mineral contents except for Cu. Increased amounts of N caused gradual increases in the investigated mineral nutrient concentrations of leaves compared with the N_0 control treatment except for K and Cu contents of the leaves. Leaf N contents increased with increasing N rates except for no nitrogen treatment. This is probably because of lack of transport due to insufficient water to transport the organic compounds to other parts of the plants. Boogaard and Thorup-Kristensen (1997) reported that a higher nitrogen uptake by cauliflower crop resulted in higher total nitrogen concentrations in the leaves and in the curds. Sharma and Chandra (2004) declared that the chlorophyll content in leaves, N, P, Ca, Zn, Fe, protein and TSS contents in cauliflower curds, and ascorbic acid content increased with increasing plant spacing and N level.

In agreement with the findings of Everaarts and Moel (1995b), leaf K contents decreased with increased N rates, gradually due to antagonism between N uptake especially as NH_4^+ and K^+ ions. This result is consistent with the findings of Kulsum et al. (2007). They concluded that K content in all plant organs of blackgram increased up to 60 kg ha^{-1} and then further increases in nitrogen caused reduction in K content. Badr and Talaab (2008) declared that Na-induced reduction in K uptake in plants is a competitive process and sodium-induced K deficiency has been implicated in growth and yield reductions of various crops. Compatible with this declaration, while the K contents were decreased, Na contents were increased by increased N rates up to 150 kg N ha^{-1}.

Although it was not statistically significant, the higher the irrigation levels, with respect to mean separation test, the lesser N and K content of cauliflower leaves. In contrast, the higher irrigation amounts up to the full irrigation enhanced leaf P, Ca, Mg, Na, Cu, Fe, Mn and Zn contents. However, excess water applications reduced leaf Cu, Fe, Mn and Zn contents, slightly. The highest leaf N, Mg, P, Fe and Zn contents were found in $N_{225} \times Kcp_{1.0}$ interaction plots which was in agreement with the highest cauliflower curd yield.

Fertilizer productivity

Fertilizer use efficiency (FUE) of cauliflower decreased with increasing N applications in N treatment plots. This can be related to dilution effect of better growth and larger biomass production. Everaarts and Moel (1995b) declared that the N use efficiency decreased with increasing N application rate. The values of FUE in irrigation treatments showed linear increases from Kcp_0 (non irrigation) to $Kcp_{1.0}$ (full irrigation) plots. However, excessive water applications in $Kcp_{1.25}$ plots had a negative effect on FUE. The highest FUE value was determined in $N_{75} \times Kcp_{1.0}$ interaction plots (Table VIII). Cai-yan et al. (2008) declared that the nitrogen and phosphate use efficiency was higher in 225 kg N ha^{-1}, 112.5 kg P_2O_5 ha^{-1}, 281.25 kg K_2O ha^{-1} applied plot than in the 450 kg N ha^{-1}, 225 kg P_2O_5 ha^{-1}, 337.5 kg K_2O ha^{-1} plot.

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