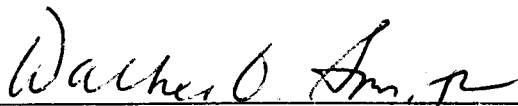


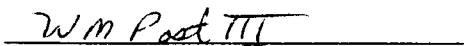
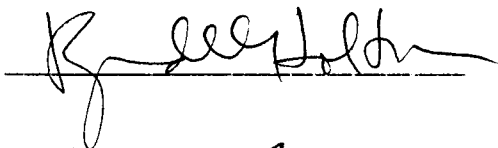
To the Graduate Council:

I am submitting herewith a thesis written by Shuhua Hu entitled "The Effects of Irradiance on Nitrate Uptake and Dissolved Organic Nitrogen Release by Phytoplankton in the Ross Sea." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.



Walker O. Smith, Jr., Major Professor

We have read this thesis and
recommend its acceptance:



Accepted for the Council:



Associate Vice Chancellor
and Dean of The Graduate School

THE EFFECTS OF IRRADIANCE ON NITRATE UPTAKE AND DISSOLVED ORGANIC
NITROGEN RELEASE BY PHYTOPLANKTON IN THE ROSS SEA

A Thesis

Presented for the

Master of Science

Degree

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Shuhua Hu

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ABSTRACT

Laboratory and field experiments have been conducted to examine the effects of irradiance on nitrate uptake and subsequent dissolved organic nitrogen (DON) release by Phaeocystis sp. and phytoplankton in the Ross Sea, Antarctica. Laboratory experiments were performed under controlled light and temperature conditions using unialgal cultures of Phaeocystis sp. obtained originally from McMurdo Station, Antarctica. The field experiments were carried out under in situ light and temperature conditions in the Ross Sea in November to December, 1994 (Cruise RSP²-94) and December, 1995 to January, 1996 (Cruise RSP²-95). ¹⁵N-labeled nitrate was used to determine nitrate uptake rates, and a modified ion retardation column (IRC) method (Bronk and Glibert 1991) was used to determine total and low molecular weight (LMW) DON release rates. The results indicate that nitrate uptake by phytoplankton in both the laboratory and the Ross Sea was strongly dependent on irradiance. The maximum nitrate uptake rate achieved by Phaeocystis sp. in the laboratory was 0.0071 h⁻¹ in 0.5 - 8 h incubations. The maximum nitrate uptake rates by phytoplankton in the Ross Sea for the two cruises were 0.0089 h⁻¹ and 0.0033 h⁻¹, respectively. Photoinhibition of nitrate uptake at high irradiance levels was observed in both laboratory experiments and field experiments in the Ross Sea. An average of 8 to 19% of the nitrate taken up by Phaeocystis sp. and phytoplankton in the Ross Sea was released as DON (total DON) which resulted in a significant underestimate of new production. Total DON release rates increased with irradiance in the

laboratory and the Ross Sea. However, the effects of irradiance on DON release were not as strong as those on nitrate uptake. In addition, while the LMW DON release by Phaeocystis sp. in the laboratory was high and dependent on irradiance, the LMW DON release rates in the Ross Sea were extremely low and were not dependent on irradiance. Estimates of new production in Antarctic waters clearly need to include DON release, and by quantifying this flux a more complete understanding of the region's role in global carbon cycles can be achieved.

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NOMENCLATURE

F	natural abundance of ^{15}N
I	irradiance
I_0	mean surface irradiance during the 24 h incubation
I_m	optimal irradiance level
K_t	half saturation constant
T	time
V	specific nitrate uptake rate
V_{DON}	specific DON release rate
V_m	maximum specific nitrate uptake rate
V_s	maximum specific nitrate uptake rate in absence of inhibition
α	initial slope of the curve
β	slope of inhibition part of the curve
ρ	absolute nitrate uptake rate
ρ_{DON}	absolute DON release rate

Abbreviations

DIW	deionized water
DON	dissolved organic nitrogen
IRC	ion retardation column
LMW	low molecular weight
PN	particulate nitrogen
TCA	trichloroacetic acid

CHAPTER I

INTRODUCTION

Most models of coupled atmospheric-oceanic processes suggest that the ocean plays a significant role in controlling atmospheric carbon dioxide concentration and hence global climate (Broecker and Peng 1986, Keir 1989, Keeling and Shertz 1992, Kagan 1995). It is estimated that marine phytoplankton remove 30 gigatons of carbon annually from the surface of the ocean through primary production (Berger et al. 1989). Therefore, the role of marine phytoplankton in the global carbon cycle and in climate change is currently the subject of an intensive international research effort (Vezina, 1994).

In general, marine primary production can be classified as new production (defined as the fraction of the total primary production that is dependent on allochthonous N sources, principally nitrate) and regenerated production (that fraction fueled by autochthonous N sources, principally ammonium) (Dugdale and Goering 1967). New production is of particular interest not only because nitrate is often the dominant N source throughout the Ross Sea (Nelson and Smith 1986, Smith 1991) and Antarctic (Rönnner et al. 1983, Koike et al. 1986, Smith and Nelson 1990), but also because at steady state only the sinking flux of particulate organic carbon fixed by new production can be identified as a biologically-mediated transport of carbon to the deep ocean (Eppley and Peterson 1979, Berger et al. 1989). Hence, determination of nitrate uptake rates is one way to estimate new

production and the flux of particulate organic carbon (Chavez and Barber 1987).

Phytoplankton growth in polar oceans is strongly constrained by the in situ environmental conditions (Smith and Harrison 1991), as is the uptake of nitrate. The ambient concentration of the available nitrate and irradiance may all affect the nitrate uptake rate. Because in the Ross Sea the concentrations of nitrate are high enough ($\geq 20\mu\text{M}$) to be considered non-limiting (Smith 1991), this study shall focus on the effect of irradiance on nitrate uptake.

Irradiance plays a poorly understood role in the uptake of nitrogenous nutrients by phytoplankton. MacIsaac and Dugdale (1969, 1972) investigated the interactions of irradiance and inorganic nitrogen in controlling the nitrate uptake by phytoplankton in a variety of waters, including the eastern tropical Pacific, coastal upwelling of Peru, and the Mediterranean. They found that "the uptake of nitrate in natural populations of marine phytoplankton was strongly light dependent (MacIsaac and Dugdale 1972)." Keene et al. (1991) also observed that irradiance was the most important environmental factor in regulating the nitrate uptake in the Arctic and Polar Fronts of the Greenland Sea. Muggli and Smith (1993) reported a detailed study on the effects of irradiance on nitrate uptake by phytoplankton in the Fram Strait of the Greenland Sea. Their results strongly confirmed the light-dependence of nitrate uptake by phytoplankton in the polar regions. Nevertheless, there have been many other studies conducted both in the Arctic (Kristiansen and Lund 1989, Smith and Kattner 1989) and in the Antarctic (Glibert et al. 1982a, Nelson and

Smith 1986) that suggested that the uptake of inorganic nitrogen is only weakly dependent on irradiance. Glibert et al. (1982a) measured nitrate uptake rates in the Scotia Sea, Antarctica, and found no significant differences among the nitrate uptake rates at different irradiance levels (0.1 to 100% of the surface irradiance). Nelson and Smith (1986) found that nitrate uptake rates in the Ross Sea at 0.1% light depth remained significant percentages of the surface rates. Therefore, further studies on the effects of irradiance on nitrate uptake by phytoplankton in the polar regions are needed.

The first quantitative attempt in describing the relationship between the uptake of inorganic nitrogen and irradiance was made by MacIsaac and Dugdale (1972). They described the relationship between nitrate uptake and irradiance by the Monod equation (Monod 1942), which was the same form of hyperbolic equation used for substrate-limited uptake (Dugdale 1967), with the parameters given in units of irradiance rather than the concentration of substrate:

$$V_m = V(K_t + S)/S \quad (1)$$

where

V_m = maximum velocity of uptake

V = specific velocity of uptake of nitrate

S = light intensity

K_t = the irradiance level at which $V = V_m/2$

This equation was in many cases able to describe adequately the nitrate uptake by natural populations of marine phytoplankton

(MacIsaac and Dugdale 1969). However, high irradiance levels can have an inhibitory effect on the uptake of nitrogenous nutrients as observed in many empirical studies (Priscu 1984, 1989, Dodds and Priscu 1989, Muggli and Smith 1993). The initial model proposed by MacIsaac and Dugdale (1972) did not allow for any inhibitory response of nitrogen uptake to high irradiance levels. Thus, Priscu (1989) further extended this model by including terms for dark uptake and photoinhibition:

$$N^B = N_s^B (1 - e^{-a})e^{-b} + D^B \quad (2)$$

where

N^B = nitrogen transport rate per unit chlorophyll

N_s^B = maximum nitrogen transport in the absence of inhibition

$a = \alpha I / N_s^B$

$b = \beta I / N_s^B$

I = PPFD (Photosynthetic Photon Flux Densities)

α = slope of the initial PPFD limited portion of the curve

β = slope of curve showing light inhibition, and

D^B = chlorophyll specific dark transport

A modified version of the Priscu's model was used by Muggli and Smith (1993) to fit the irradiance vs. nitrogen uptake data:

$$V = V_s (1 - e^{-a})e^{-b} \quad (3)$$

where:

V = specific nitrogen uptake rates (h^{-1})

V_s = maximum specific nitrogen uptake rate in absence of inhibition (h^{-1})

I = % surface irradiance

$a = \alpha I / V_s$

$b = \beta I / V_s$

α = initial slope of curve, and

β = slope of inhibition part of curve

The model accurately described the effects of irradiance on nitrate and ammonium uptake rates in the Greenland Sea.

Release of dissolved organic nitrogen (DON) by the phytoplankton after reduction of inorganic nitrogen is an important process in the nitrogen cycle of marine environments (Suzuki et al. 1985, Antia et al. 1991, Bronk and Glibert 1991). It has been found for a variety of environments, including the oceanic Caribbean Sea, the coastal Southern California Bight, and the Chesapeake Bay, that an average of twenty-five to forty-one percent of the inorganic nitrogen incorporated by phytoplankton was released as dissolved organic nitrogen during spring or late autumn (Bronk et al. 1994). The recognition and determination of DON release rates has had a tremendous influence on the study and estimation of new production as well as the transport of dissolved organic matter to depth.

Traditionally, nitrogen uptake rates are measured with the stable isotope ^{15}N ($^{15}\text{NO}_3^-$ or $^{15}\text{NH}_4^+$). A common observation in ^{15}N tracer

experiments is that all the ^{15}N label added to start the incubation is not always accounted for the end of the experiment (Glibert et al. 1982b, Ward et al. 1989). Researchers have hypothesized several fates for this missing ^{15}N . Glibert et al. (1982b) identified remineralization as one potential pathway leading to loss of $\text{NH}_4\text{-}^{15}\text{N}$ to nitrate or nitrite pools in estuarine waters. Laws (1984) and Ward et al. (1989) suggested that $\text{NO}_3\text{-}^{15}\text{N}$ label was lost when small cells containing ^{15}N passed through the GF/F filters used in uptake studies (nominal pore size $0.7\ \mu\text{m}$). However, recent studies had showed that DON release could be a more important pathway for the "missing ^{15}N " --- both $^{15}\text{NH}_4$ and $^{15}\text{NO}_3$ (Bronk and Glibert 1993, 1994). In some cases DON release accounted for 90 to 100% of the missing nitrogen in the final budget (Collos, 1992). Consequently, new production may be significantly underestimated with the traditional ^{15}N techniques due to the release of DON. The degree of underestimation will depend on the natural DON release process as well as any artifacts which induce DON release.

It is particularly important to consider the effect of DON release on new production estimates during phytoplankton blooms. During blooms a large fraction of the annual nitrogen flux from the surface waters as particles occurs. It has been found that the release of DON increased markedly when the bloom began to decline (Bronk et al. 1994). Therefore, larger rates of DON release will create larger underestimates of nitrate uptake rates and new production.

The mechanisms of DON release by phytoplankton include direct release, cell lysis, viral infection and cellular disruption (Procter

and Fuhrman 1990, Suttle et al. 1990), or sloppy feeding by micro- or mesozooplankton (Lampert 1978, Roy et al. 1989). Environmental factors such as light, temperature, nutrient limitation, as well as zooplankton grazing may all affect the release of DON from phytoplankton cells. Any sampling or experimental condition that imparts a stress to cells (such as changes in temperature, light, or salinity) can result in artificially enhanced release rates.

Dissolved organic nitrogen includes low molecular weight (LMW; <10,000 Daltons) compounds, high molecular weight (>20,000 Daltons) compounds, and other forms. Numerous studies have investigated the uptake and release of individual components of DON, such as amino acids (Wheeler and Kirchman 1986, Fuhrman 1987, 1990), urea (McCarthy et al. 1977, Hansell and Goering 1989), and DNA (Paul et al. 1987). Studies of individual DON components are useful to assess the turnover of the DON pool but they do not provide information of the cycling of biologically labile materials. Indeed, these studies focus on a very small fraction of the total DON pool and probably underestimate the importance of the DON pool as a whole (Bronk and Glibert 1991). Furthermore, the LMW DON component can be separated from the total DON by combining ultrafiltration with the ion retardation method to determine the LMW DON release rate (Bronk and Glibert 1991). The difference in LMW and total DO^{15}N release rates and their relationship to one another is a useful index in understanding what release processes would be important under various conditions. When the rate of LMW DO^{15}N release represents a relatively high percentage of the total DO^{15}N release rate, we can expect that direct release by

phytoplankton is the dominant release process, because direct release by phytoplankton as exudates from actively growing phytoplankton is often dominated by LMW components (Mague et al. 1980). Conversely, if total DO^{15}N release rates were significantly higher than rates of LMW DO^{15}N release, it is more likely that processes such as cell lysis, viral infection, or sloppy feeding were occurring and dominating DON flux.

The effects of irradiance on DON release are not clear. Collos et al. (1992) had reported an extremely high DON release rate during a light period. In their laboratory experiment with an 6 - 18 h light/dark period, DON concentration in the medium first increased from undetectable values at time zero to $\sim 30\ \mu\text{M}$ after 4 h in the light period, then remained constant until 12 h. Thereafter a large decrease occurred during the next 6h in the dark, then a rapid increase leading to a final DON increase of $\sim 28\ \mu\text{M}$ at 24 h. The light-dependence of DON release had also been detected in the studies by Chan and Campbell (1978). However, one has to interpret the high release rates of DON in the light carefully (Collos et al. 1992), because filtration artifacts and stress conditions may occur (Sharp 1977). Moreover, different components of DON seem to respond differently to irradiance. Flynn and Al-Amoudi (1988) studied the release of free amino acids (FAA) by the diatom Phaeodactylum tricornutum Bohlin under light or dark conditions, and found that over 24 h the cells incubated in light showed a marked decrease in content of all amino acids but lysine, while cells incubated in darkness kept much greater levels of most amino acids, with little decrease in levels of some, such as aspartate

and histidine, and increases in others (e.g., ornithine and lysine). By 48 h the major amino acid present in the medium in which cells were incubated in the light was histidine, whereas the amount of FAA in the medium of the dark incubated cells contained more serine and glycine. Further studies of the effects of irradiance on absolute release rate of DON and its composition are needed.

The study of irradiance effects on nitrate uptake and subsequent DON release was performed in the Ross Sea, Antarctica during November 10 ~ December 8, 1994 and December 17, 1995 ~ January 15, 1996. The Ross Sea was chosen because it is characterized by 1) significant biogenic production and seabed accumulation (Ledford-Hoffman et al. 1986, Nelson and Smith 1986), 2) relatively confined boundaries, 3) water circulation that is reasonably well understood, and 4) close proximity to a major Antarctic support facility (McMurdo Station). The phytoplankton blooms in the Ross Sea are dominated by Phaeocystis or diatoms at different locations (Leventer and Dunbar 1996). Phaeocystis blooms are predominant in the central and southeastern regions, whereas diatoms dominate the north and southwest (Smith et al. 1996). Phaeocystis-dominated blooms occur earlier, and shift to diatom-dominated blooms later in the season. This study attempted to quantify the effect of irradiance on nitrate uptake and subsequent dissolved organic nitrogen release by phytoplankton in the Ross Sea. In the Southern Ocean, while nutrient concentrations are high throughout the seasons, light is limited to relatively short periods. Moreover, even during 24 h photo periods, light intensity decreases rapidly with depth (at many coastal locations, irradiance drops to below 0.1% of

the surface value by 45 m; Nelson and Smith 1986). Irradiance is one of the major limiting factors in phytoplankton growth and uptake of nitrate in the Southern Ocean (Smith and Sakshaug 1990). Subsequent dissolved organic nitrogen release by phytoplankton utilizing nitrate was also studied. The measurement of DON release rates is very useful in correcting the estimation of new production by traditional ^{15}N methods, and a better understanding of the DON release and its response to irradiance may help to explain the discrepancy between ^{15}N -based and ^{14}C -based new production estimates and the imbalance of specific carbon:specific nitrogen uptake ratio to observed C:N elemental ratio as frequently observed in field studies (Harrison et al. 1985, Collos and Slawyk 1986, Smith & Harrison 1991).

CHAPTER II

MATERIALS AND METHODS

This study was conducted on natural assemblages of phytoplankton in the Ross Sea, Antarctica, from November 10 ~ December 8, 1994 (Cruise RSP²-94) and December 17, 1995 ~ January 15, 1996 (Cruise RSP²-95) following preliminary laboratory experiments. The study area included open waters as well as waters covered by varying concentrations of ice. Continuous daylight occurred during both cruises. Station locations for the RSP²-94 and RSP²-95 cruises are shown in Figures 1 and 2.

Laboratory experiments

Before the cruises preliminary laboratory experiments on nitrate uptake and subsequent DON release were performed using unialgal cultures of *Phaeocystis* sp. obtained from the Center for Culture of Marine Phytoplankton, Bigelow Laboratory for Ocean Sciences. Cultures were grown in f/2 medium (Guillard and Ryther, 1962) at 4°C and continuous light of 155 $\mu\text{E m}^{-2} \text{ s}^{-1}$. Samples for determination of the concentrations of nitrate, particulate nitrogen, and chlorophyll were collected at the beginning of the experiments, and then an addition of ca. 40% enrichment of ¹⁵N-labeled NaNO₃ was made to the medium. The culture was then transferred into 250 ml polycarbonate incubation bottles (each contained 100 ml culture), immediately placed into a set of screened incubators in the cold room, and incubated for 0.5, 1, 3,

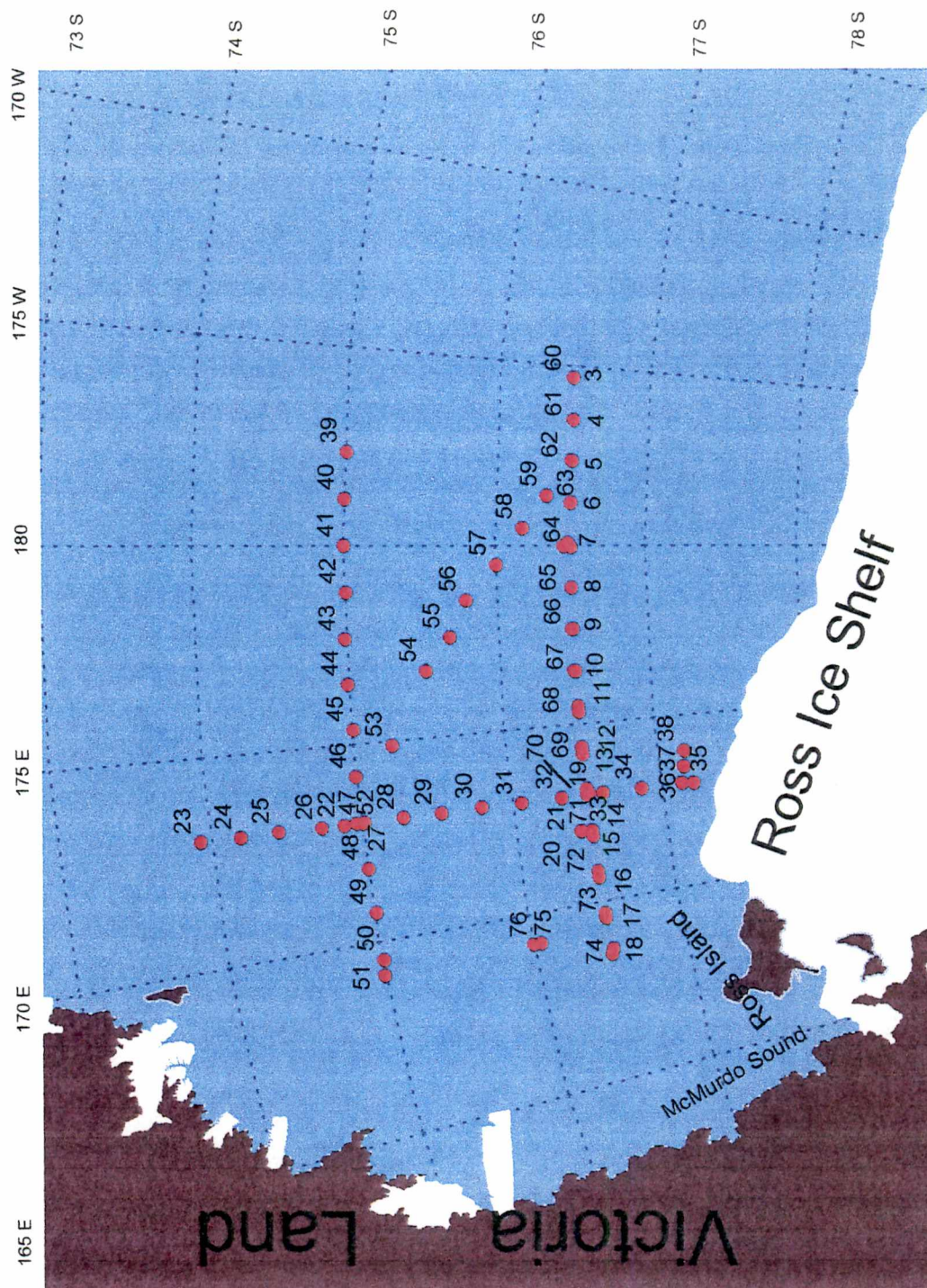


Figure 1. Locations of the Stations sampled during Cruise RSP²-94.

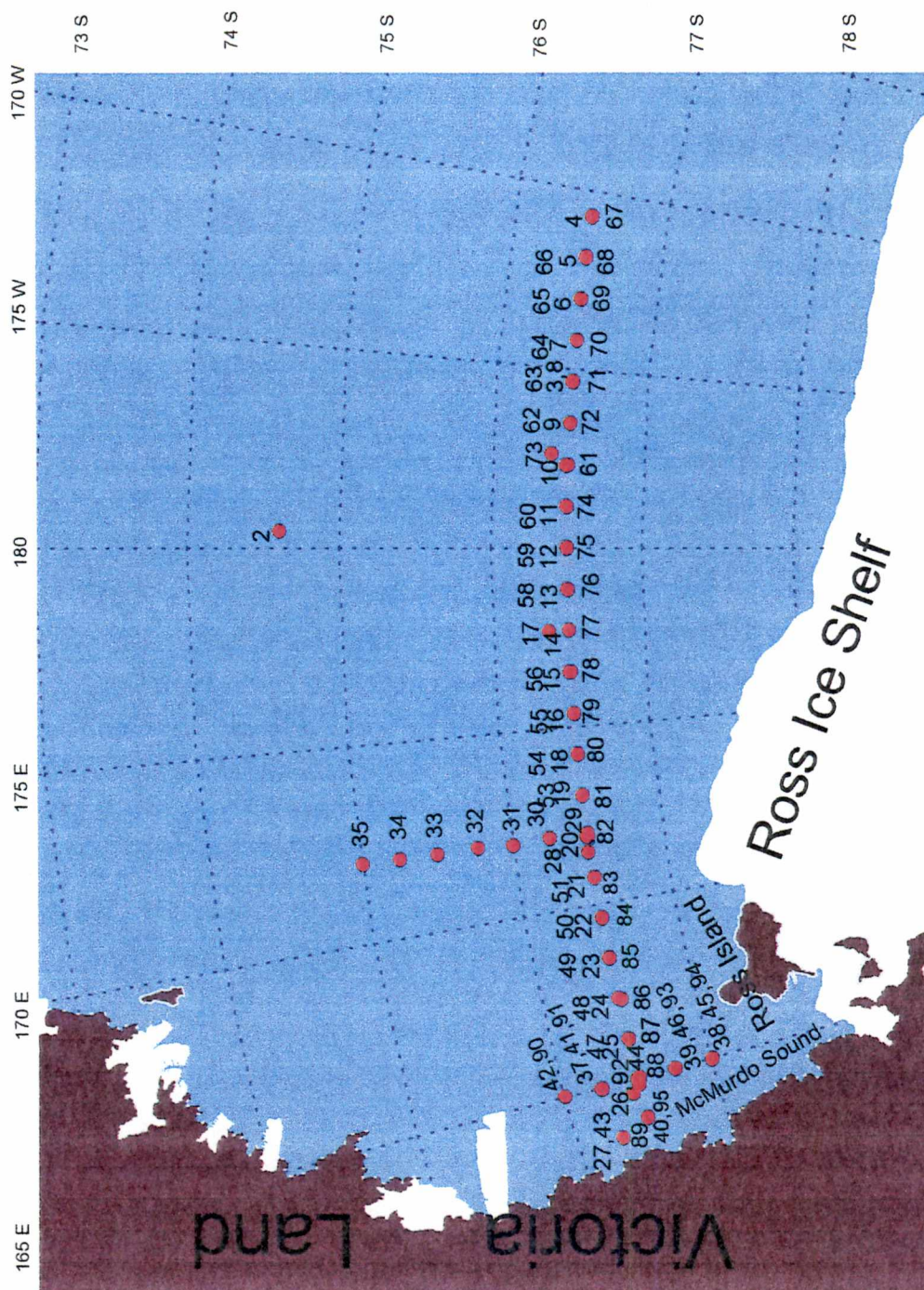


Figure 2. Locations of the stations sampled during RSP²-95.

5, or 8 hours. The incubator was covered by neutral density screens simulating the irradiance levels of 100, 50, 30, 15, 5, 1, or 0.1% of the full irradiance. After incubation two samples from each irradiance level were filtered through precombusted GF/F filters, sealed in a precombusted vial, and dried at 60°C, for the determination of nitrate uptake rate and ^{15}N atom per cent enrichment of the intracellular DON pool. A third sample was filtered through 0.2 μm Nuclepore filter, and the filtrate was collected to determine total and low molecular weight (LMW) DON release rates.

Field Experiments

Water samples were obtained from 10-liter Niskin bottles mounted on a rosette which housed a conductivity-temperature-depth (CTD) system. A total of 24 Niskin bottles were attached to the rosette. Generally, water samples were taken for the productivity casts within the euphotic zone which corresponded to 100, 50, 30, 15, 5, 1, or 0.1% of the surface irradiance. The contents of the Niskin bottles were drained into polycarbonate carboys before subsampling. Subsamples for determination of ambient nutrients were taken first, followed by subsamples for ^{15}N incubations and for determination of chlorophyll, particulate nitrogen, and particulate carbon. Clear 500-ml polycarbonate bottles were used for ^{15}N -experiments.

The irradiance vs. nitrate uptake and DON release experiments were conducted under in situ irradiance conditions in on-deck incubators which were covered with neutral density screens simulating

irradiance levels representing 100, 50, 30, 15, 5, 1, or 0.1% of surface irradiance. The ambient concentrations of nitrate in the water samples were obtained shortly after the waters were collected and processed by a rapid flow Alpkhem Autoanalyzer (Codispoti et al. 1991). An addition of ca. 40% enrichment of ^{15}N -labeled NaNO_3 was made to each sample, and the 500-ml polycarbonate bottles were placed immediately into screened incubators and incubated for 24 hours. After incubation two subsamples of 200 ml from each bottle were filtered onto precombusted (450°C, for 4 h) 25-mm Whatman GF/F filters for determination of nitrate uptake rate and ^{15}N -atom per cent enrichment of the intracellular DON pool, and a third subsample of 100 ml was filtered through a 0.2 μm Nuclepore filter to determine the DON release rates. During RSP²-94 the third subsample was filtered through a double GF/F filter (two GF/F filters placed in series) at most stations to increase the filtration rate. After filtration the filters were placed in precombusted vials dried and stored at 60°C until analyzed, and the filtrates were frozen at -80°C and stored at -20°C until analyzed. Separate samples for the measurement of chlorophyll and particulate carbon and particulate nitrogen were filtered at the beginning of all experiments.

Nitrate Uptake

Nitrate uptake rates were determined using emission spectrometry (Nelson and Smith 1986). Sample preparation and preparation of the discharge tubes followed a modified Dumas combustion method (Fiedler

and Proksch 1975). Discharge tubes were made of Pyrex glass with an outer diameter of 7 mm. The tubes were precombusted at 560°C for 2h to eliminate any organic materials adhering to the surface. Dried GF/F filters were ground with copper oxide (an oxidant) (Aldrich #31043-3) in a Retsh MM-2 Mixer Mill for 3-5 minutes to obtain a homogenous mixture of the sample and copper oxide. An appropriate volume of ground sample was then added into each discharge tube (containing small amount of combusted calcium oxide) based on the amount of particulate nitrogen in that sample. The discharge tubes were evacuated using a Kamazawa sampling device, sealed in vacuum, and combusted at 560°C for 4 h. Copper oxide was used to convert all forms of organic nitrogen present into nitrogen gas upon combustion, whereas the calcium oxide absorbed any water vapor and other gases generated during combustion, which would interfere with the emission spectrum of the nitrogen gas.

The percentage of ^{15}N -atoms present in the nitrogen gas generated during combustion and oxidation was determined using a Jasco N-150 emission spectrometer. After ignition, peaks representing ^{14}N - ^{14}N molecules, ^{14}N - ^{15}N molecules, and ^{15}N - ^{15}N molecules were displayed on a computer screen, and the ^{15}N percentage was calculated using the following equations:

$$R = I^{28} / (I^{29} \times M) \quad (4)$$

$$^{15}\text{N atom \%} = 100 / (2R + 1) \quad (5)$$

where

R = corrected ^{14}N - ^{14}N to ^{14}N - ^{15}N ratio

I^{28} = the height of the ^{14}N - ^{14}N peak

I^{29} = the height of the ^{14}N - ^{15}N peak

M = multiplier value the instrument used for $^{29}\text{N}^{30}\text{N}$

The specific nitrate uptake rates were calculated using the equation:

$$V = (1/T) \ln[(^{15}\text{N}_{\text{enr}} - F) / (^{15}\text{N}_{\text{enr}} - ^{15}\text{N}_s)] \quad (6)$$

where

V = specific nitrate uptake rate (h^{-1})

$^{15}\text{N}_s$ = atom% ^{15}N in the sample

$^{15}\text{N}_{\text{enr}}$ = atom% ^{15}N in the initially labeled nitrate

F = natural abundance of ^{15}N , and

T = incubation time (h)

(Dugdale and Wilkerson 1986). The absolute nitrate uptake rate was then calculated by multiplying the specific uptake rate with the concentration of particulate nitrogen measured at the beginning of the experiments:

$$\rho = V \times \text{PN} \quad (7)$$

where

ρ = absolute nitrate uptake rate ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)

PN = concentration of particulate nitrogen ($\mu\text{g N l}^{-1}$)

A modified version of the Priscu's model (Muggli and Smith 1993) was used to fit the irradiance vs. nitrate uptake data. The data were

fitted by non-linear regression analysis in SPSS and Axum which used equation (3) and Marquardt's algorithm to determine the best fit. The maximum specific nitrate uptake rate predicted by the model was then calculated by analogy to the equation used by Platt et al. (1980):

$$V_m = V_s (\alpha / (\alpha + \beta)) (\beta / (\alpha + \beta))^{(\beta / \alpha)} \quad (8)$$

The predicted optimal irradiance level at which maximum uptake occurs was given by the equation:

$$I_m = (V_s / \alpha) \ln((\alpha + \beta) / \beta) \quad (9)$$

(Priscu 1989). The half-saturation constant K_t (the irradiance level at which the nitrate uptake rate is one half of the maximum uptake rate) for saturation response was determined using parameters obtained from equations (3) and (8).

DON Release

Eight ion retardation columns (IRC) (Kontes #420400-2520, 2.5 cm x 2.5 cm) containing 40 g of resin (Biorad #143-7824, AG 11 A8, 50-100 mesh size) were used to separate DON components using a modified ion retardation method (Bronk and Glibert 1991). A needle (B-D Precision Glide 22G1) was attached to the bottom of each column to allow a slow and constant flow rate (about 2.5 ml min⁻¹). A sample size

of 15 ~ 2 × 10 ml was used in the IRC filtration to collect enough ¹⁵N-labeled dissolved organic nitrogen for ¹⁵N emission spectrometry analysis. Following the sample, 15 ~ 20 ml deionized water (DIW) was used to rinse the IRC to prevent the release of any inorganic nitrogen components. The IRC eluates were collected in 125 ml Pyrex flasks and neutralized to pH of 7 to 8 with 1N HCL, and then heated to reduce the sample volume to less than 1 ml. The concentrated eluates were then spotted onto precombusted GF/F filters, the filters were placed in precombusted vials, sealed, and dried at 60°C for ¹⁵N analysis.

The ion retardation resin was regenerated after each sample by passing 30 ml of 1M NaOH through the column, followed by 1000 ml of deionized water. The 1M NaOH was passed through the column while the needle was attached to maintain a slow flow rate. The needle was removed before the DIW was added to produce a better flushing of the resin.

The low molecular weight DON was separated from total DON by a Centriprep ultrafilter (Amicon #4304; 1000 Dalton cutoff). A 2 × 10 ml subsample was passed through the ion retardation column following the protocol outlined above, and then the eluate was filtered through the Centriprep ultrafilter under a centrifugal force of 3000 × g. The Centriprep ultrafiltrate was collected into a 125 ml Pyrex flask, concentrated to less 1 ml by boiling, and spotted onto a GF/F filter. The filter was then sealed and dried at 60°C in a precombusted vial for ¹⁵N analysis.

The intracellular DON pool was isolated by grinding one of the GF/F filters from ¹⁵N experiments with 0.37M trichloroacetic acid (TCA)

in a tissue homogenizing tube (Clayton et al. 1988). TCA was used to precipitate the protein contents. The homogenate was neutralized with 1M NaOH and centrifuged for 10 minutes. The separated liquid was then filtered through a Centriprep ultrafilter and an ion retardation column, and the eluate was heated in a 125 ml Pyrex flask to reduce the volume to less than 1 ml. The concentrated eluate was then spotted onto a GF/F filter, sealed, and dried at 60°C in a precombusted vial for ^{15}N analysis.

The atom% of ^{15}N in the DON samples was measured on the JASCO N-150 emission spectrometer using the same methods as outlined previously except that a shorter discharge tube (10 to 12.5 cm) and a larger sample (3 ~ 4 ml) was used because of relatively small total amount of nitrogen in the DON samples. The concentration of DON at the end of incubation was obtained by subtracting the concentration of inorganic nitrogen (nitrate, nitrite, and ammonium) from the total nitrogen determined using the persulfate oxidation method (Valderrama 1981). The concentrations of nitrate and nitrite were determined using the method of Parsons et al. (1984).

To calculate DON release rates, an equation adapted from equations to calculate the dissolved inorganic nitrogen uptake rates (Dugdale and Goering 1967) was used (Bronk and Glibert 1991):

$$\rho_{\text{DON}} = (1/T) \frac{{}^{15}\text{N-DON}_e - F}{{}^{15}\text{N-DON}_i - F} [\text{DON}] \quad (10)$$

where

$$\rho_{\text{DON}} = \text{absolute DON release rate } (\mu\text{g N l}^{-1} \text{ h}^{-1})$$

$^{15}\text{N-DON}_e$ = atom % ^{15}N in the extracellular DON pool

$^{15}\text{N-DON}_i$ = atom % ^{15}N in the intracellular DON pool

DON = the concentration of DON (total or LMW) at the end of
incubation ($\mu\text{g N l}^{-1}$)

The specific DON release rates were calculated using the equation as
the following:

$$V_{\text{DON}} = \rho_{\text{DON}} / \text{PN} \quad (11)$$

where

V_{DON} = specific DON release rate (h^{-1})

ρ_{DON} = absolute DON release rate ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)

The statistical relationship between irradiance and DON release
was determined using GLM procedure of SAS (SAS Institute Inc., 1985).

CHAPTER III

RESULTS

Effects of irradiance on nitrate uptake

Laboratory experiments

Irradiance vs. nitrate uptake experiments were conducted in the laboratory under controlled light ($155 \mu\text{E m}^{-2} \text{s}^{-1}$) and temperature (4°C) on July 29 and October 14, 1994. Nitrate, chlorophyll, and particulate nitrogen data are provided in Appendix A-1. Results of irradiance vs. nitrate uptake rates are shown in Figures 3-7 and Appendix A-2.

The relationship between nitrate uptake and irradiance in the laboratory experiments can be described as a strong saturation response (Figures 3-7, Appendix A-2). The specific nitrate uptake rates were very low and ranged from 0.004 h^{-1} to 0.0025 h^{-1} at the lowest irradiance level, and increased dramatically until reached the maximum uptake rates (from 0.0058 to 0.012 h^{-1}) at about 20 ~ 40% of surface irradiance ($30 \sim 60 \mu\text{E m}^{-2} \text{s}^{-1}$). Photoinhibition was observed in all but the 8 h incubation.

The predicted maximum nitrate uptake rates (V_m) ranged from 0.0058 h^{-1} to 0.0095 h^{-1} , and were very close to the observed values in the experiments (Table 1). The optimal irradiance levels for nitrate uptake were from 25 to 39% irradiance ($39 \sim 60 \mu\text{E m}^{-2} \text{s}^{-1}$), and the half-saturation response constants, K_t , were from 4.5 to 10.5% irradiance (ranging from $7.0 \sim 11.2 \mu\text{E m}^{-2} \text{s}^{-1}$).

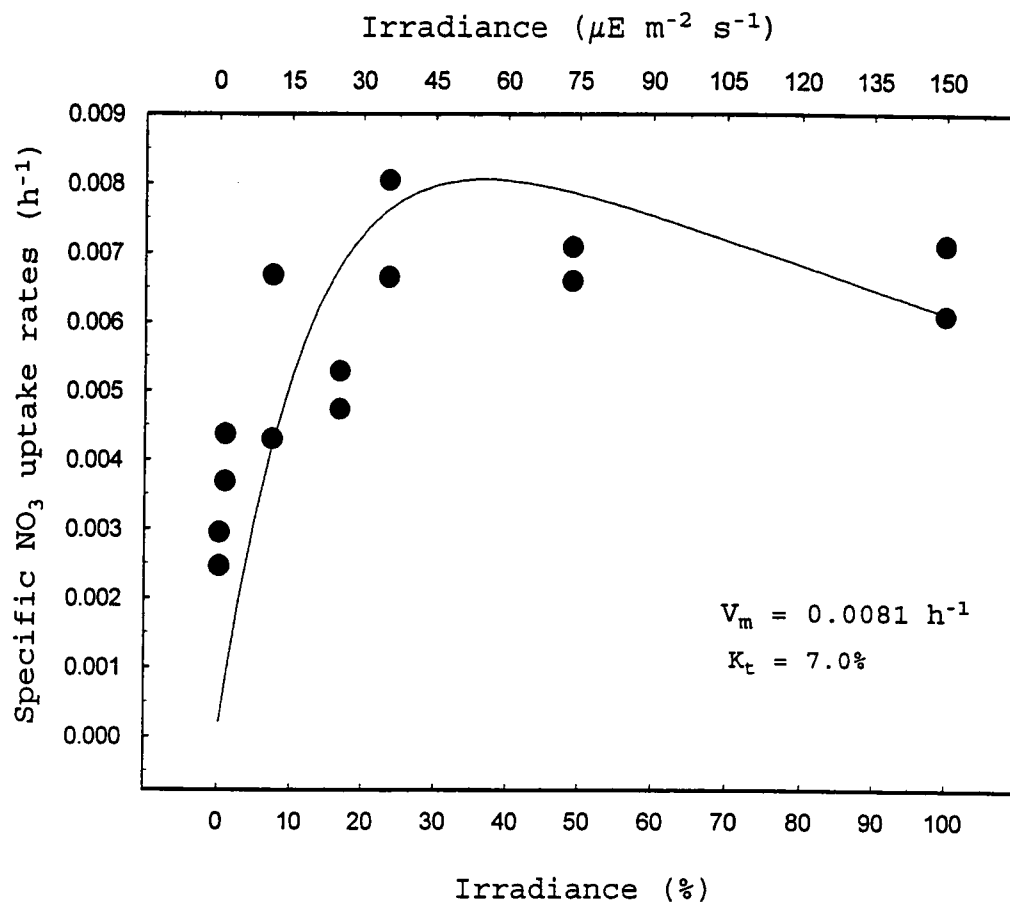


Figure 3. Relationship between specific nitrate uptake and per cent irradiance during 0.5 h incubation in the laboratory. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant.

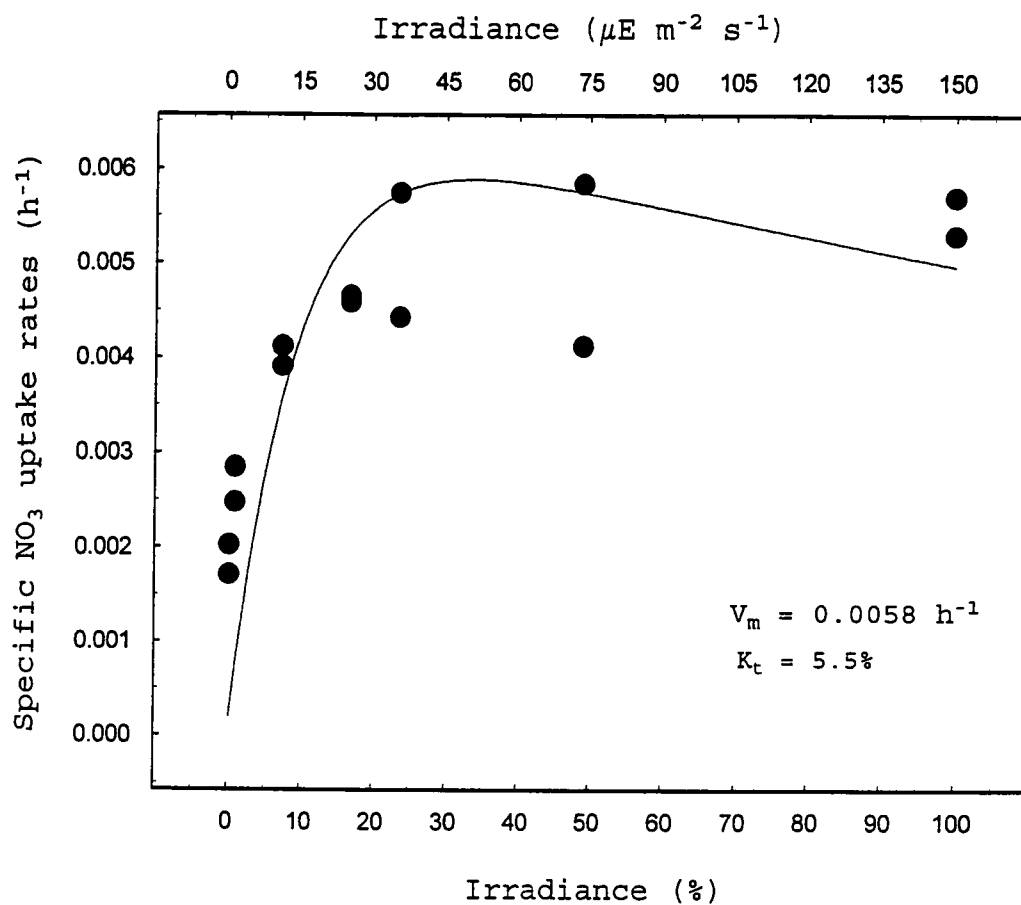


Figure 4. Relationship between specific nitrate uptake and per cent irradiance during 1 h incubation in the laboratory. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant.

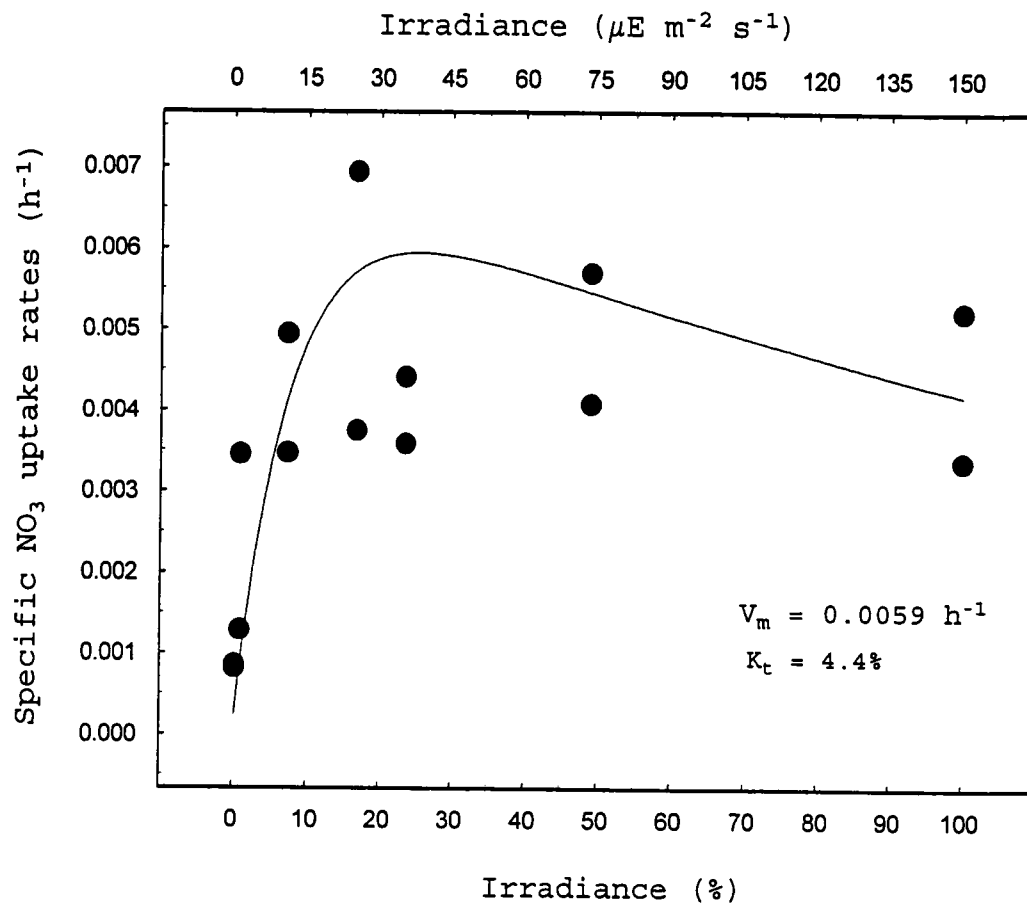


Figure 5. Relationship between specific nitrate uptake and per cent irradiance during 3 h incubation in the laboratory. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant.

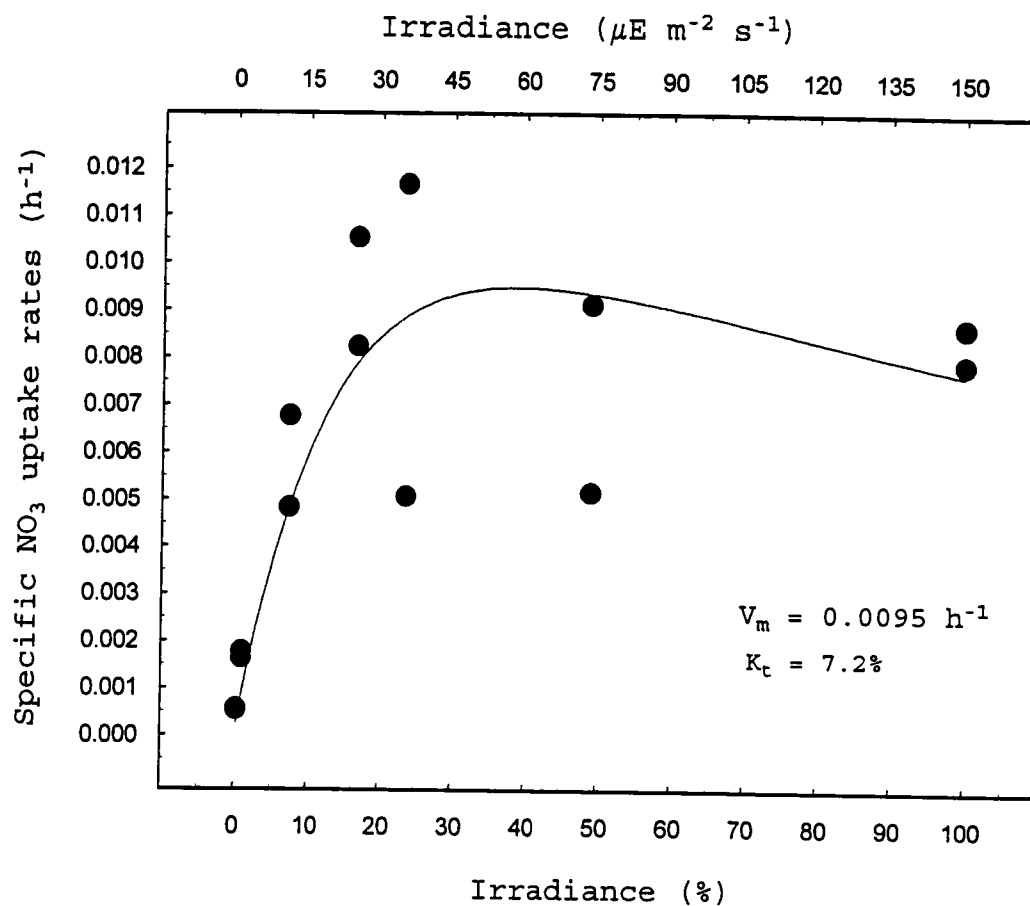


Figure 6. Relationship between specific nitrate uptake and per cent irradiance during 5 h incubation in the laboratory. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant.

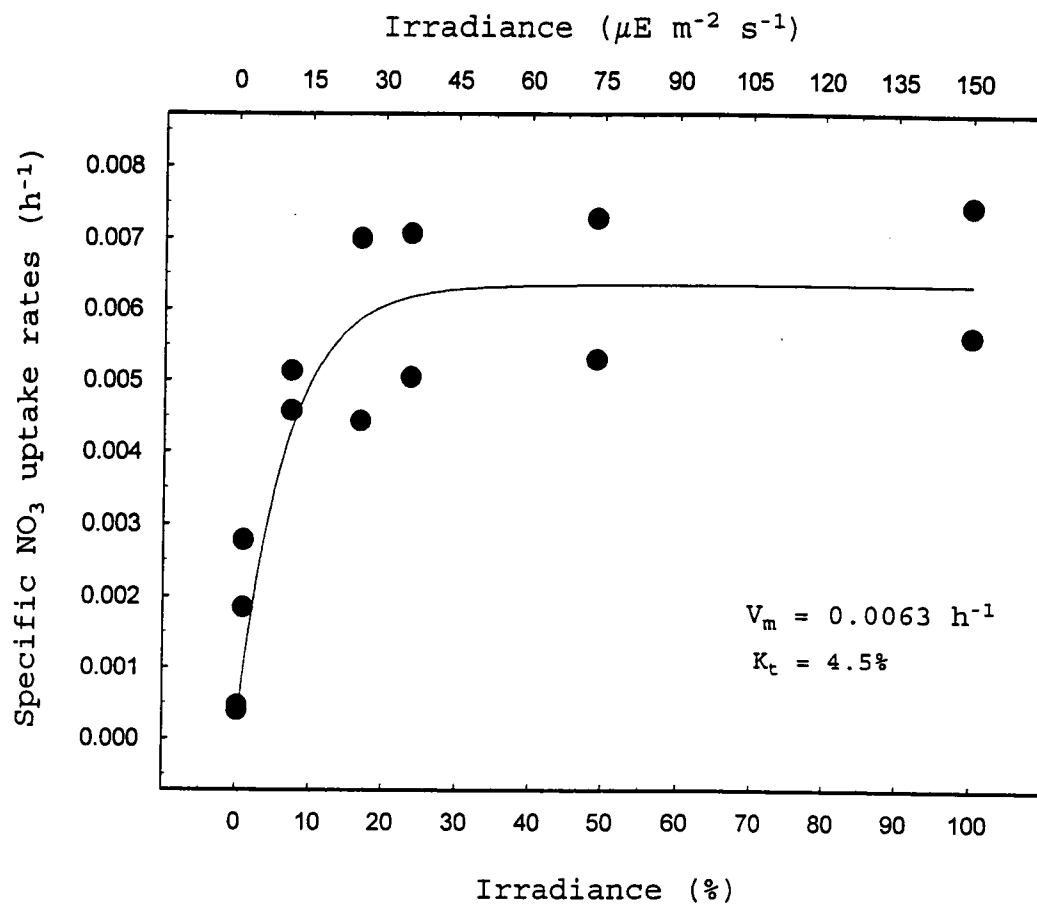


Figure 7. Relationship between specific nitrate uptake and per cent irradiance during 8 h incubation in the laboratory. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant.

Table 1. Summary of parameters for the laboratory irradiance vs. nitrate uptake experiments.

Incubation (h)	V_s (h^{-1})	α	β	V_m (h^{-1})	(%)	I_m ($\mu E\ m^{-2}\ s^{-1}$)	(%)	K_t ($\mu E\ m^{-2}\ s^{-1}$)
0.5	0.0106	0.000764	0.000058	0.0081	37	57	7.0	10.8
1	0.0067	0.000713	0.000020	0.0058	34	52	5.5	8.6
3	0.0071	0.000896	0.000037	0.0059	25	39	4.4	6.9
5	0.0120	0.000875	0.000054	0.0095	39	60	7.2	11.2
8	0.0063	0.000972	0.000000	0.0063	--	--	4.5	7.0
Mean	0.0085	0.000844	0.000034	0.0071	34	52	5.7	8.9
Sd.	0.0026	0.000104	0.000024	0.0016	6	9	1.3	2.0

RSP²-94 experiments

Irradiance vs. nitrate uptake experiments were conducted at 14 stations during RSP²-94, including Stations 9, 19, 60, 64, 70, and 72 on transect 1 (76° 30' S), Stations 25, 36, 37, and 38 on transect 2 (173° E), Stations 39, 47, 53, and 56 on transect 3 (75° S and the diagonal from Station 47 to 62) (Table 2 and Figure 1). In general, surface nitrate concentrations were high at all stations, ranging from 18.8 ~ 32 μM (Figures 8-10, Part A). The lowest nitrate concentrations were observed at Stations 64, 70 and 72 and ranged from 18.8 to 22 μM at the surface. The highest nitrate concentrations were observed at Station 9. Vertical stratification of nitrate concentration was observed at all stations except at Station 9 (Figure 8, part A; Appendix B-1). Chlorophyll data showed similar pattern as those of nitrate (Figures 8-10). The highest surface chlorophyll concentration (8.8 $\mu\text{g l}^{-1}$) was found at Stations 64, and the lowest surface chlorophyll concentration (0.29 $\mu\text{g l}^{-1}$) was observed at Station 39 (Figures 8 and 10, part B; Appendix B-1). The surface concentrations of particulate nitrogen ranged from 7.2 ~ 78.4 $\mu\text{g l}^{-1}$ (Figures 8-10). The lowest concentration was found at Station 39, and the highest concentration was found at Station 70 (Figures 9 and 10, part C; Appendix B-1).

The relationship between nitrate uptake and irradiance during RSP²-94 can be described as a strong saturation response at most stations (Figures 11-17). Specific nitrate uptake rates were very

Table 2. Transect locations of RSP²-94 and RSP²-95.

Transect No.	Locations
RSP ² -94	
1	76° 30' S
2	173° E
3	75° south and diagonal from station 47 to 62
RSP ² -95	
1	first east/west transect along 76° 30' S
2	western polynya and west/east transect along 76° 30' S
3	second east/west transect along 76° 30' S

Transect 1

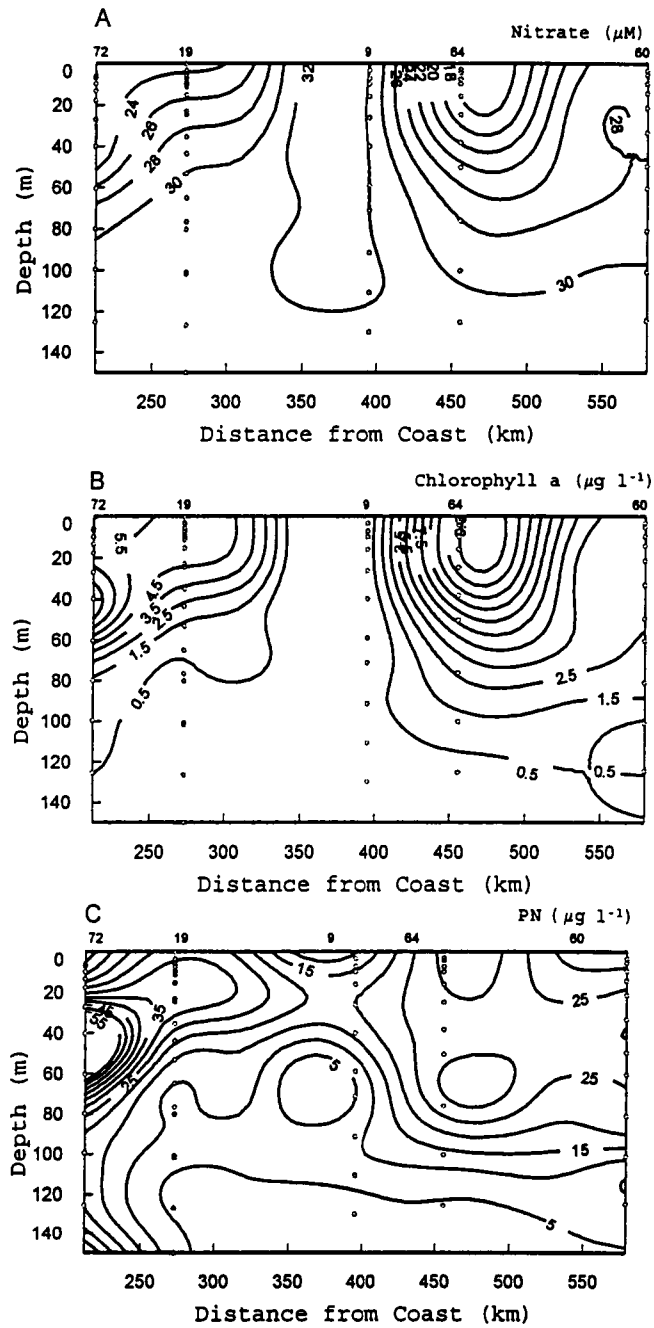


Figure 8. Distribution of nitrate, chlorophyll, and particulate nitrogen within transect 1 of RSP²-94.

Transect 2

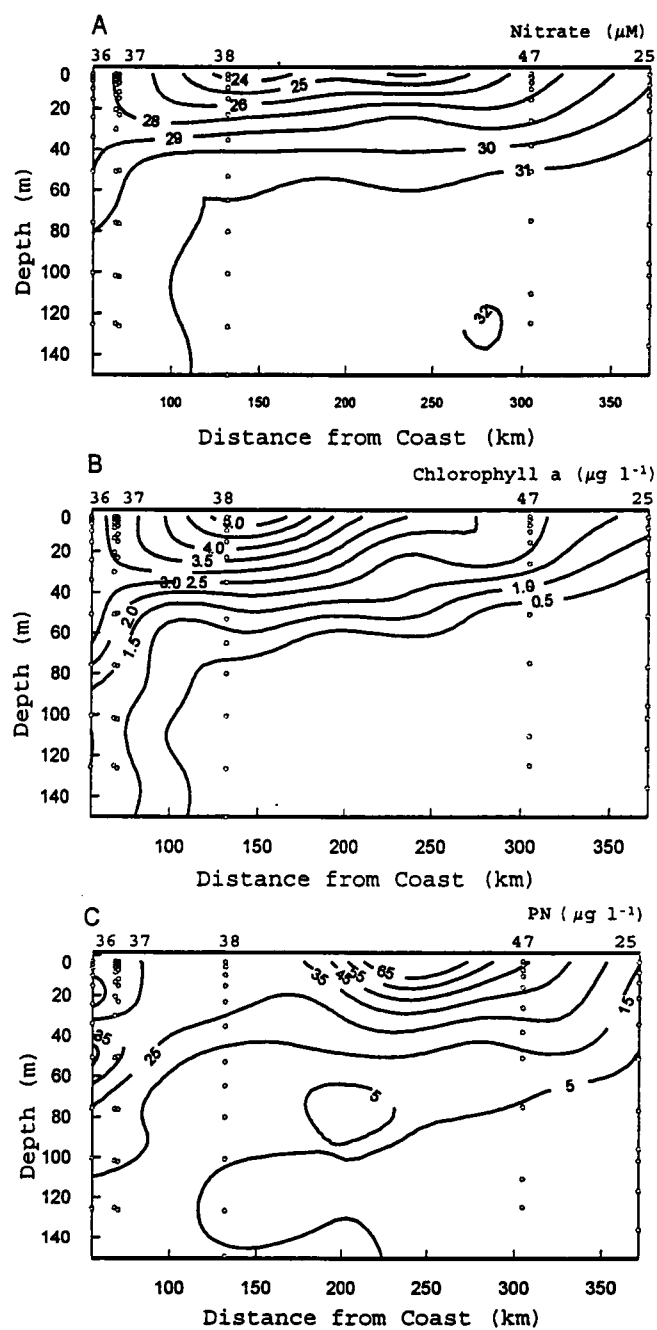


Figure 9. Distribution of nitrate, chlorophyll, and particulate nitrogen within transect 2 of RSP²-94.

Transect 3

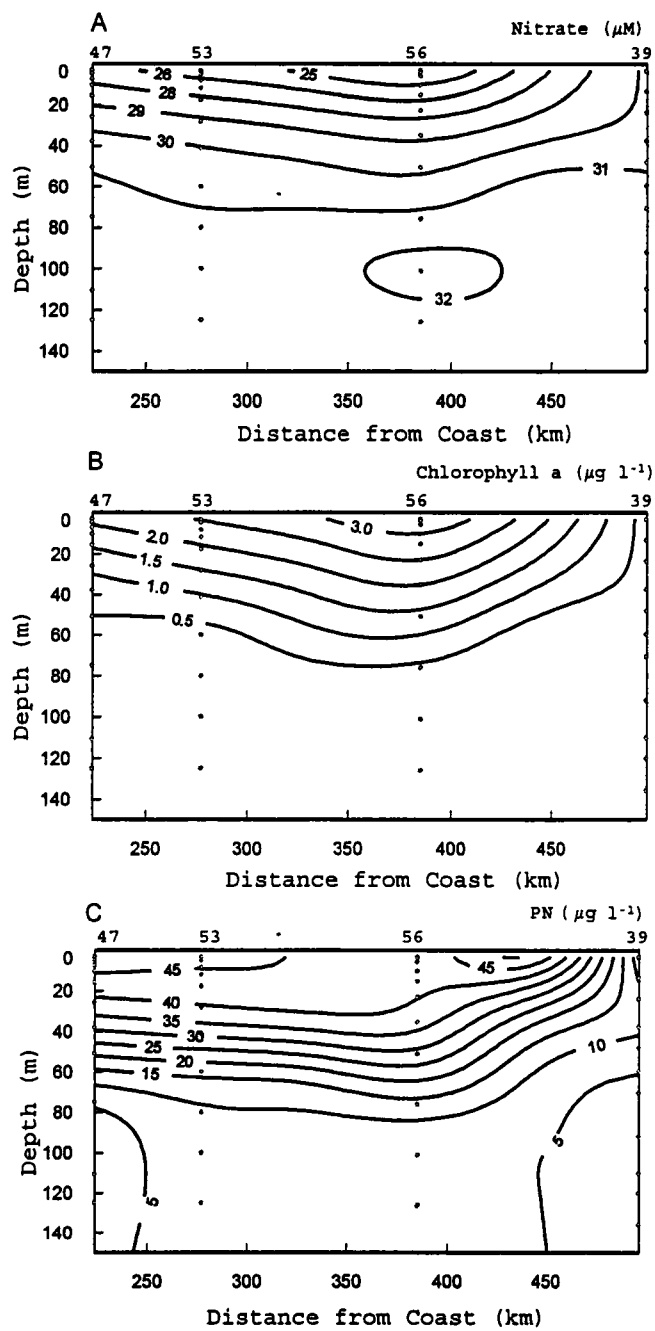


Figure 10. Distribution of nitrate, chlorophyll, and particulate nitrogen within transect 2 of RSP²-94.

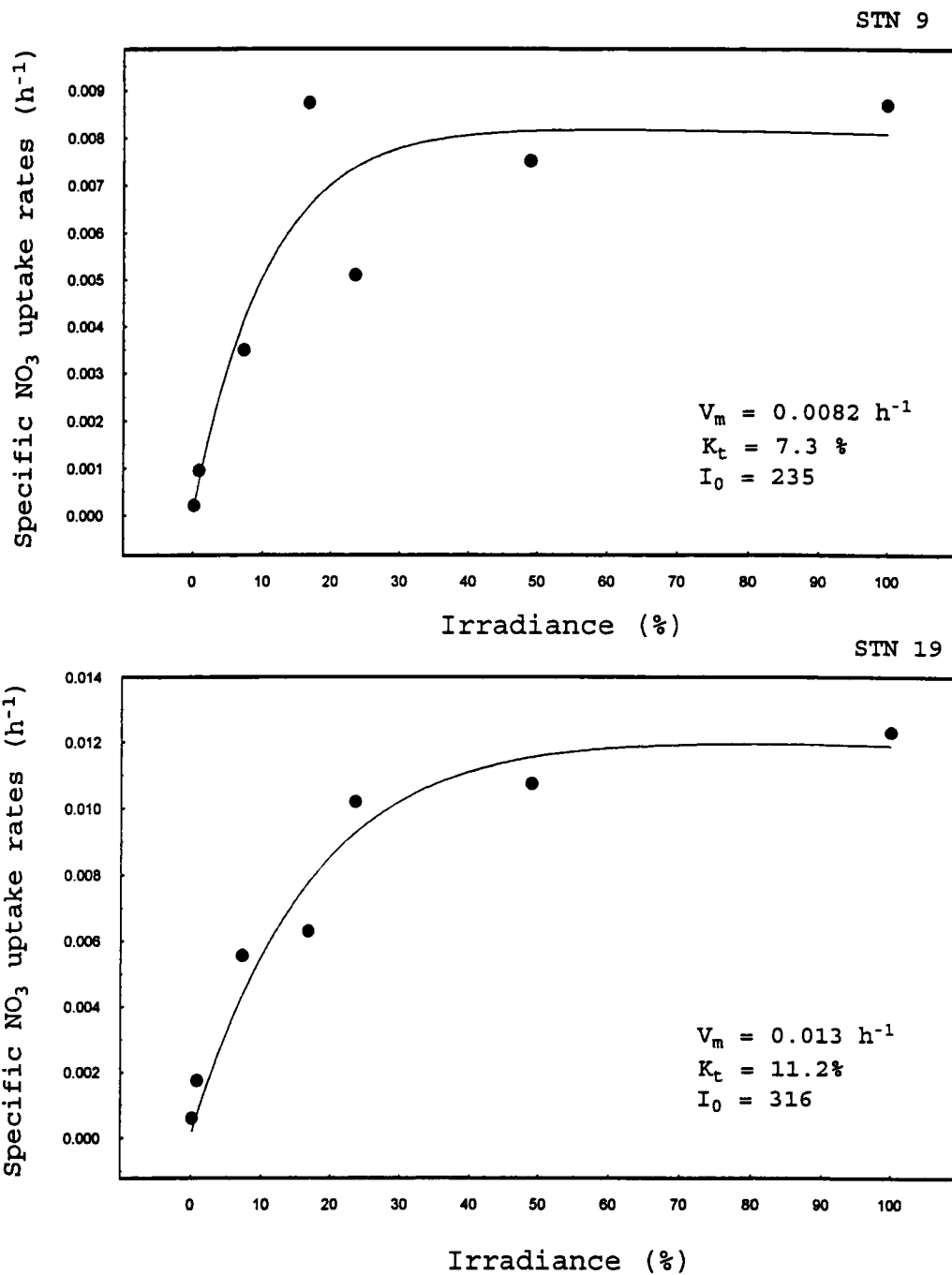


Figure 11. Relationships between specific nitrate uptake and per cent surface irradiance at stations 9 and 19 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

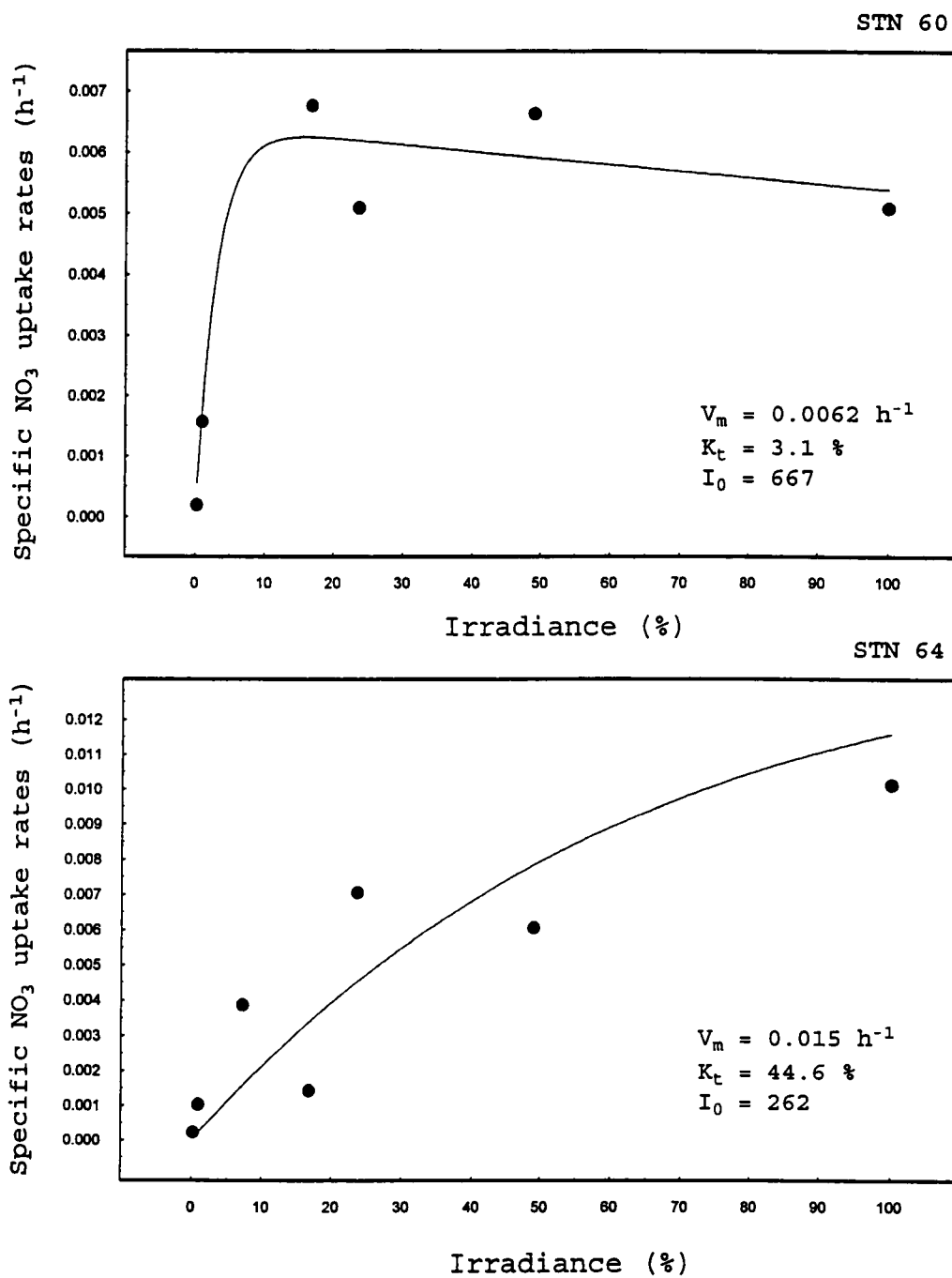


Figure 12. Relationships between specific nitrate uptake and per cent surface irradiance at stations 60 and 64 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

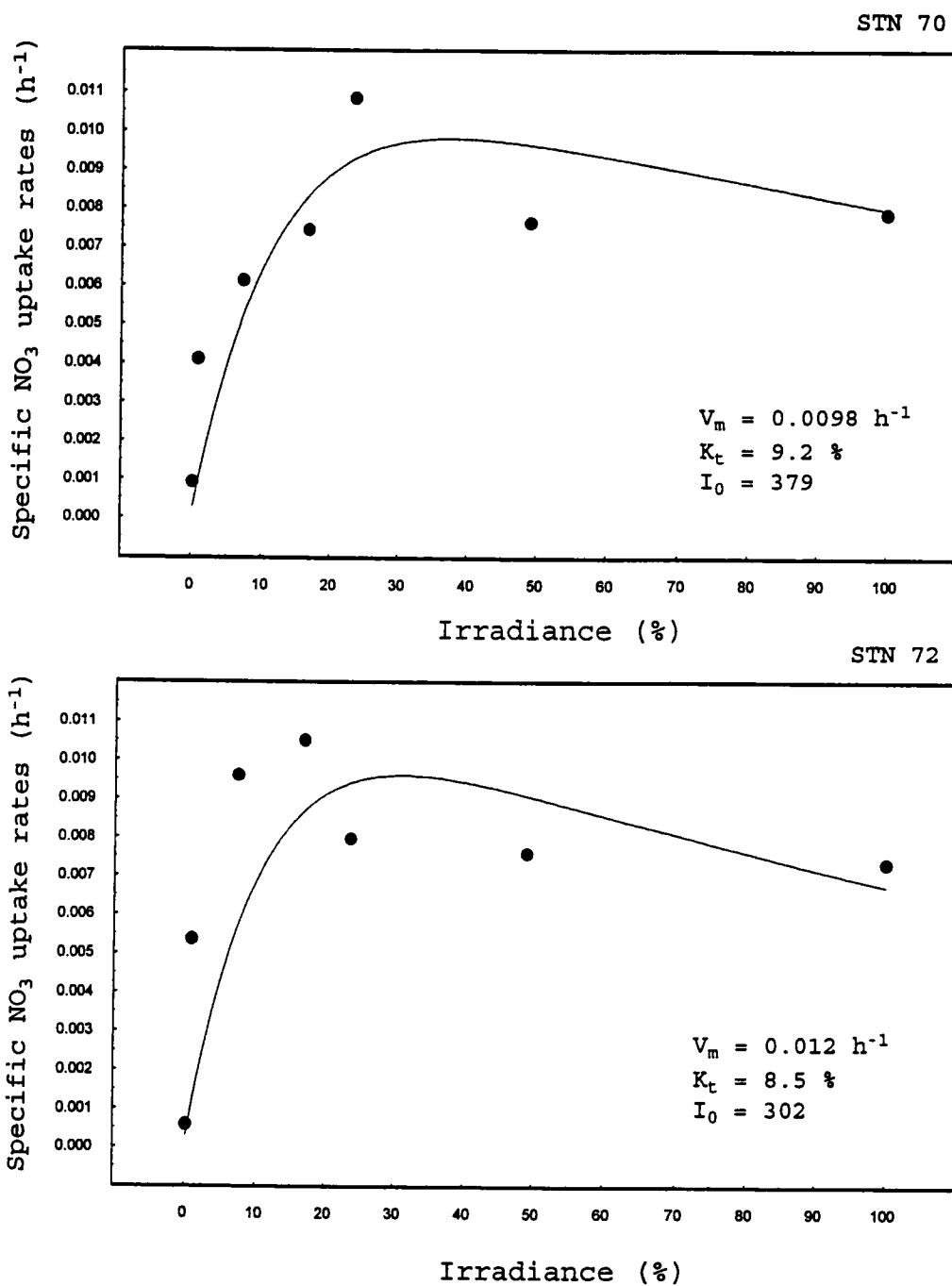
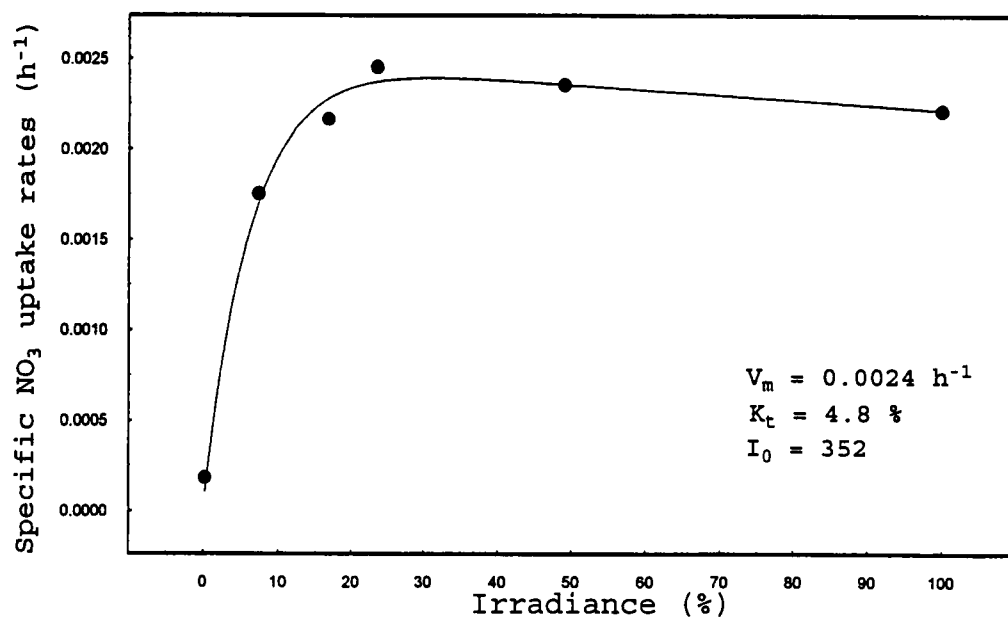


Figure 13. Relationships between specific nitrate uptake and per cent surface irradiance at stations 70 and 72 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

STN 25



STN 36

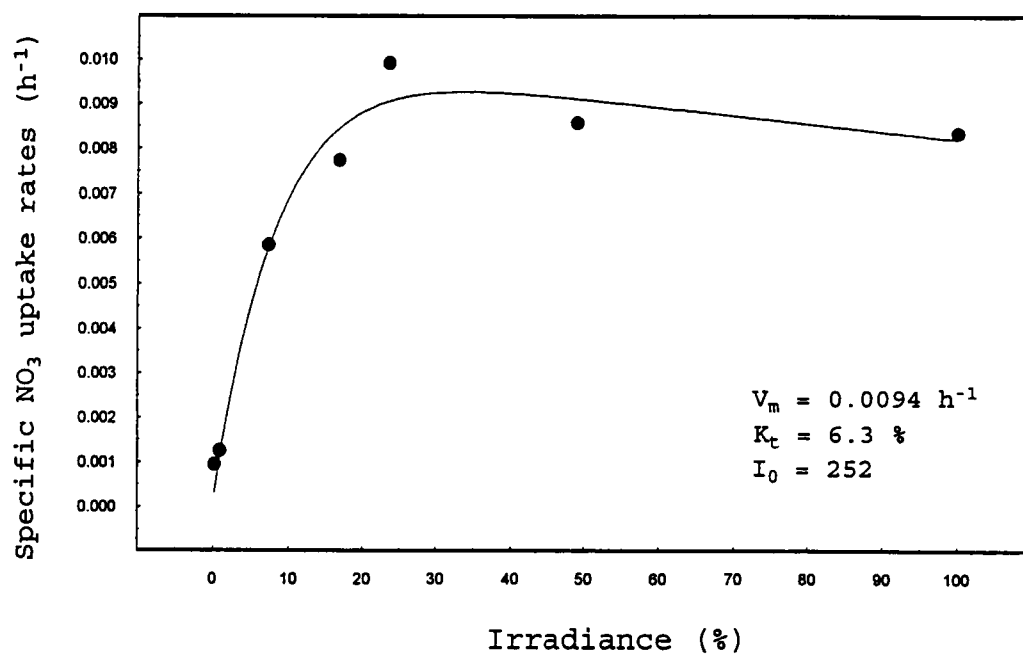


Figure 14. Relationships between specific nitrate uptake and per cent surface irradiance at stations 25 and 36 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

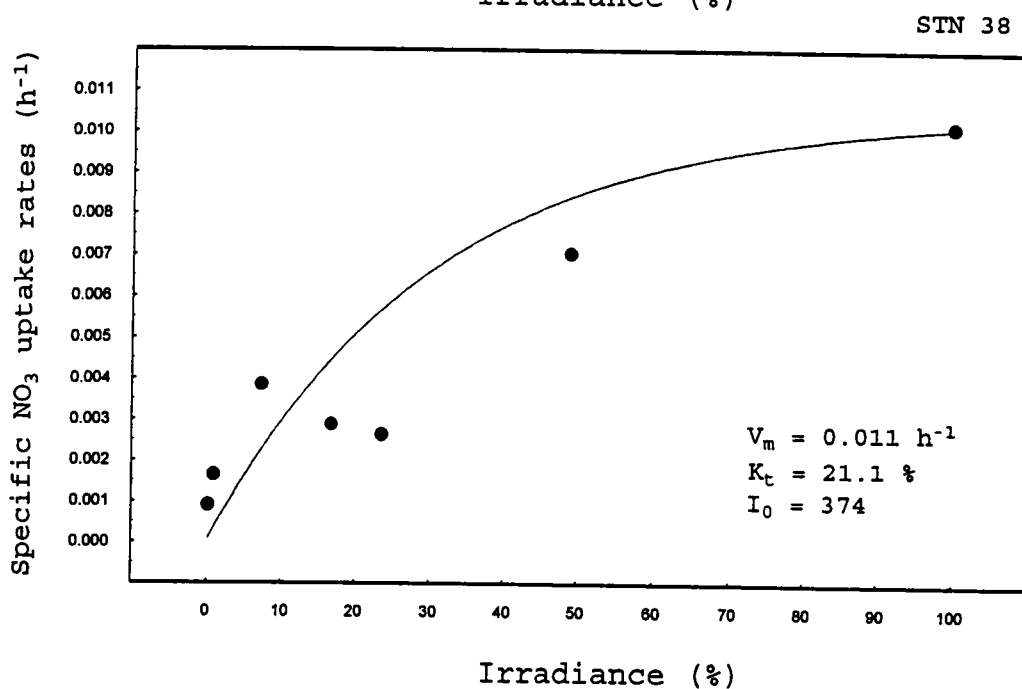
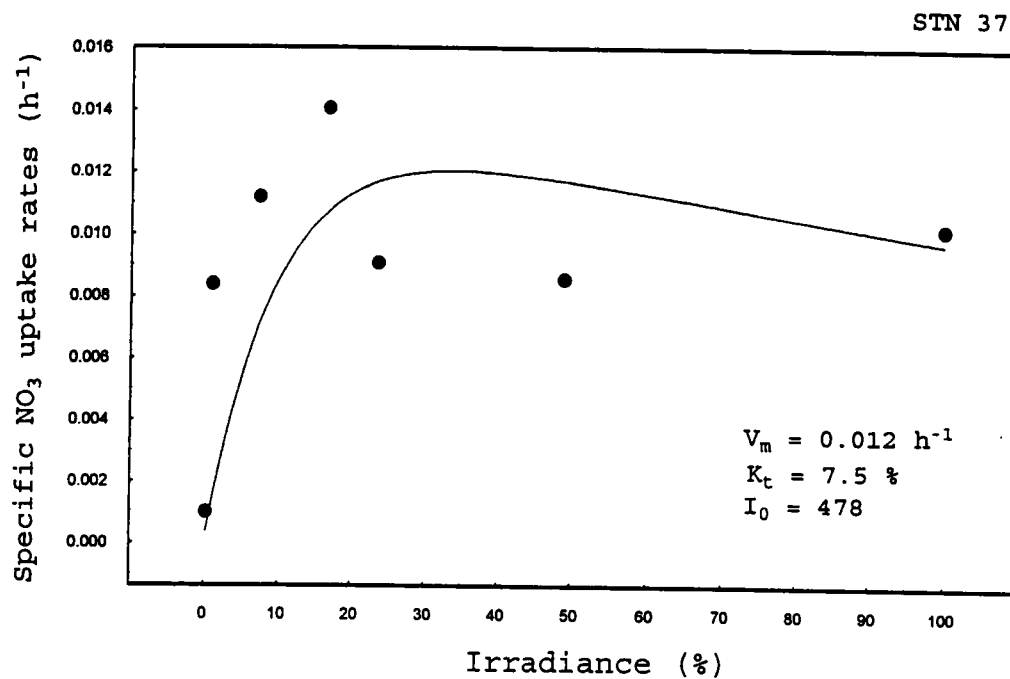


Figure 15. Relationships between specific nitrate uptake and per cent surface irradiance at stations 37 and 38 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

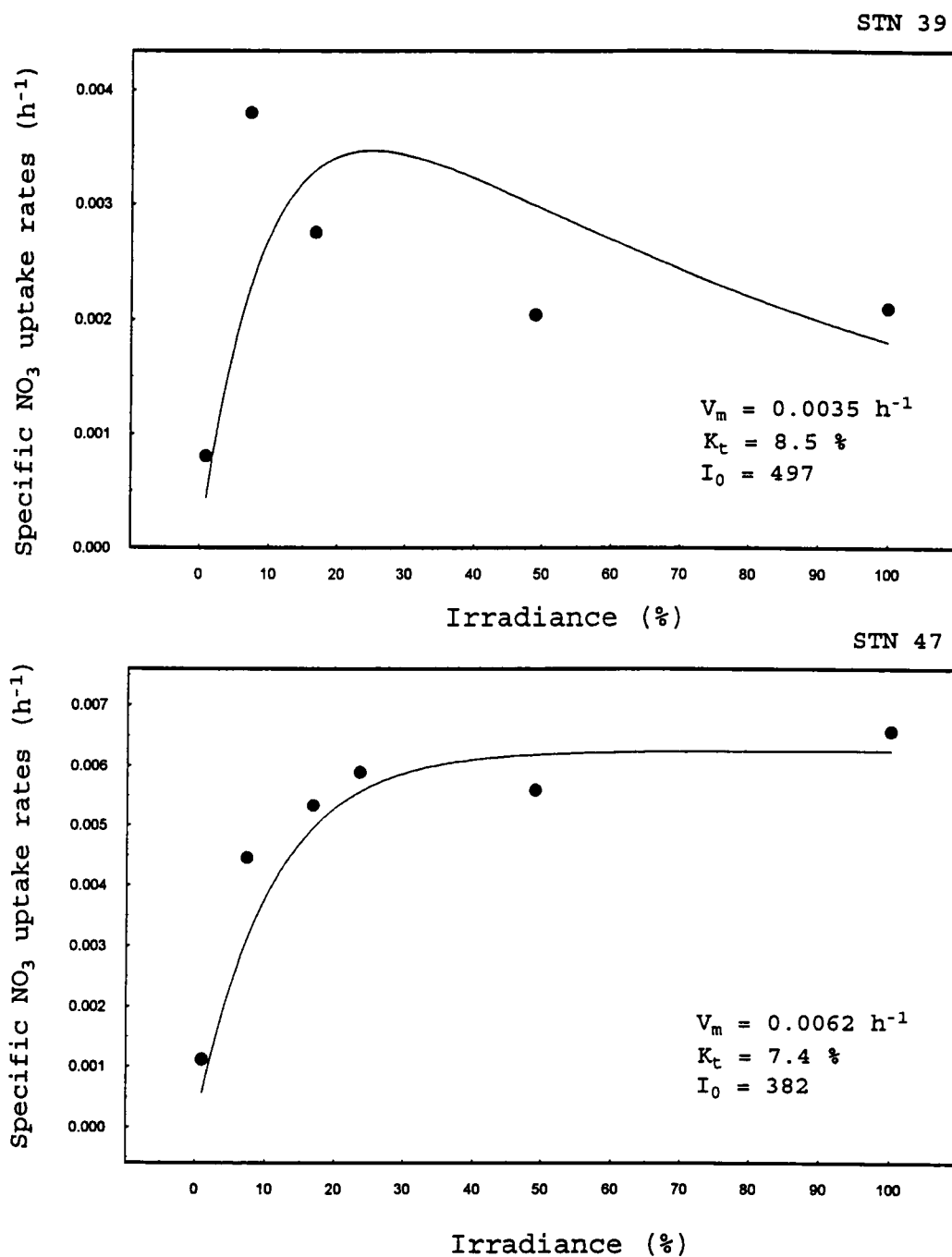


Figure 16. Relationships between specific nitrate uptake and per cent surface irradiance at stations 39 and 47 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

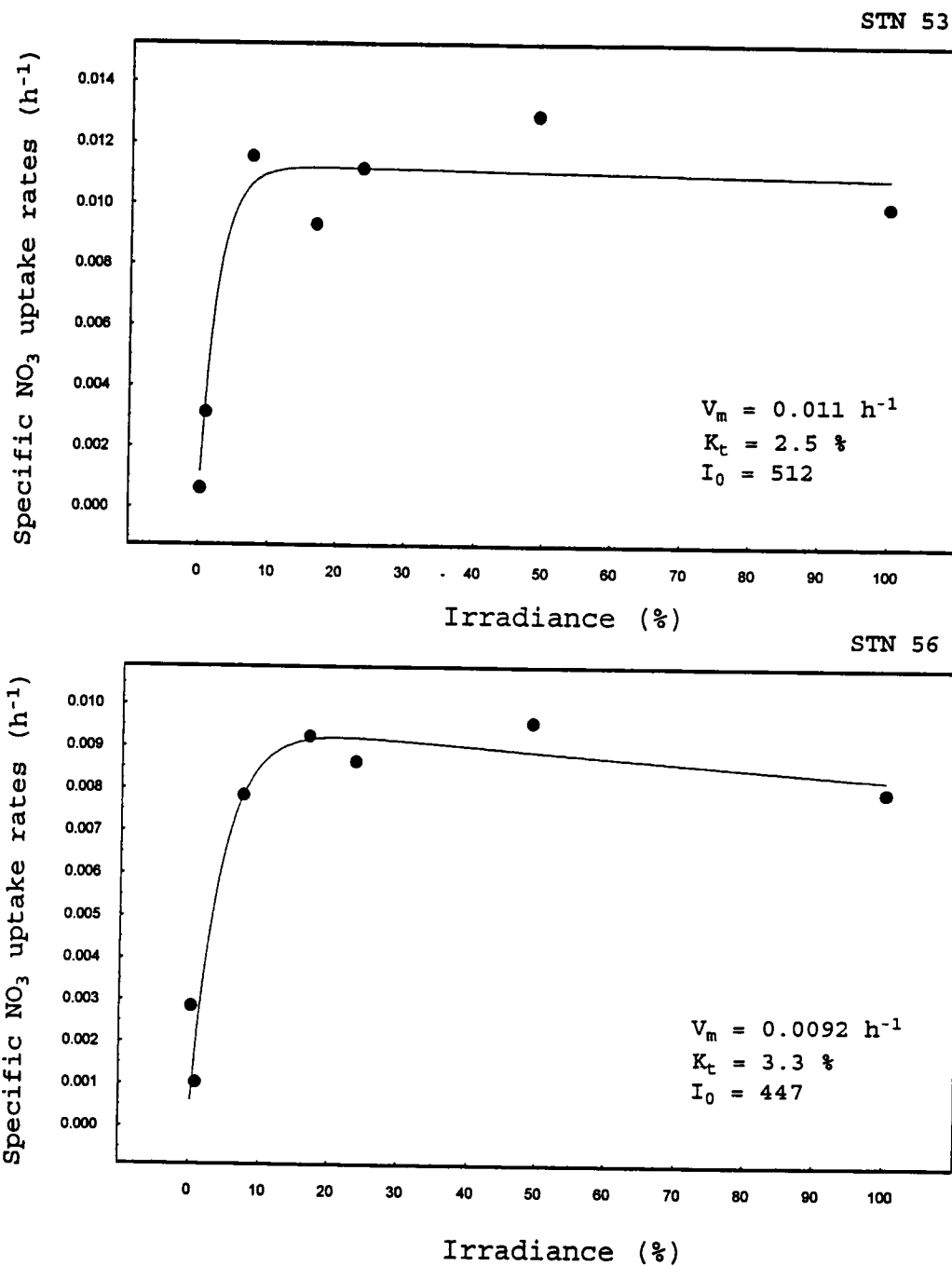


Figure 17. Relationships between specific nitrate uptake and per cent surface irradiance at stations 53 and 56 of RSP²-94. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

low, ranging from 0.0002 h^{-1} to 0.0006 h^{-1} on transect 1, 0.0002 to 0.001 h^{-1} on transect 2, and 0.0006 to 0.0009 h^{-1} on transect 3 at the lowest irradiance levels. The uptake rates increased to 0.0068 h^{-1} to 0.011 h^{-1} on transect 1, 0.0025 to 0.014 h^{-1} on transect 2, and 0.0028 to 0.013 h^{-1} on transect 3, at about 15 to 50% of surface irradiance. Photoinhibition was observed at Stations 60, 70, 72, 25, 36, 37, 39 and 56.

The predicted maximum nitrate uptake rates ranged from 0.0024 h^{-1} to 0.015 h^{-1} and were close to the experimental values (Table 3). The optimal irradiance levels for nitrate uptake were from 21 to 60% of surface irradiance (from 89 to $254 \mu\text{E m}^{-2} \text{ s}^{-1}$), and the half-saturation response constants were from 2.9 to 44.6% of surface irradiance (12.8 to $117 \mu\text{E m}^{-2} \text{ s}^{-1}$).

RSP²-95 experiments

Irradiance vs. nitrate uptake experiments were conducted at 23 stations during RSP²-95, including Stations 3, 4, 5, 9, 14, 20, 22, 23, 25 and 26 on transect 1 (first east/west transect along $76^{\circ} 30' \text{ S}$), Stations 28, 31, 35, 40, 42, 54, 58, 61, and 65 on transect 2 (western polynya and west/east transect along $76^{\circ} 30' \text{ S}$), and Stations 75, 79, 81, and 86 on transect 3 (second east/west transect along $76^{\circ} 30' \text{ S}$) (Table 1 and Figure 2). In general, the surface nitrate concentrations were lower than those of RSP²-94 and ranged from 12.4 to $25.2 \mu\text{M}$ (Figures 18-20). The

Table 3. Summary of parameters for the irradiance vs. nitrate uptake experiments of RSP²-94.

Station No.	V_g (h ⁻¹)	α	β	V_m (h ⁻¹)	(%)	I_m ($\mu E\ m^{-2}\ s^{-1}$)	(%)	K_t ($\mu E\ m^{-2}\ s^{-1}$)
9	0.0084	0.000775	0.000003	0.0082	60	141	7.3	17.0
19	0.0126	0.000728	0.000007	0.0119	80	254	11.2	35.5
25	0.0025	0.000358	0.000003	0.0024	34	119	4.5	16.0
36	0.0103	0.001157	0.000022	0.0093	35	89	5.5	13.8
37	0.0142	0.001380	0.000054	0.0120	34	162	5.9	28.0
38	0.0105	0.000346	0.000000	0.0105	-	-	21.1	78.8
39	0.0050	0.000458	0.000050	0.0035	25	125	5.0	24.6
47	0.0062	0.000584	0.000000	0.0062	-	-	7.4	28.3
53	0.0112	0.003068	0.000004	0.0111	24	125	2.5	12.8
56	0.0096	0.002053	0.000014	0.0092	23	104	3.1	13.7
60	0.0065	0.001477	0.000012	0.0062	21	142	2.9	19.3
64	0.0147	0.000229	0.000000	0.0147	-	-	44.6	116.9
70	0.0121	0.000965	0.000050	0.0098	38	143	6.8	25.7
72	0.0124	0.001097	0.000076	0.0096	31	94	5.8	17.5
Mean	0.009727	0.001048	0.000021	0.0089	37	136	9.5	32.0
Sd.	0.0035	0.000746	0.000024	0.0033	17	43	10.7	28.6

Transect 1

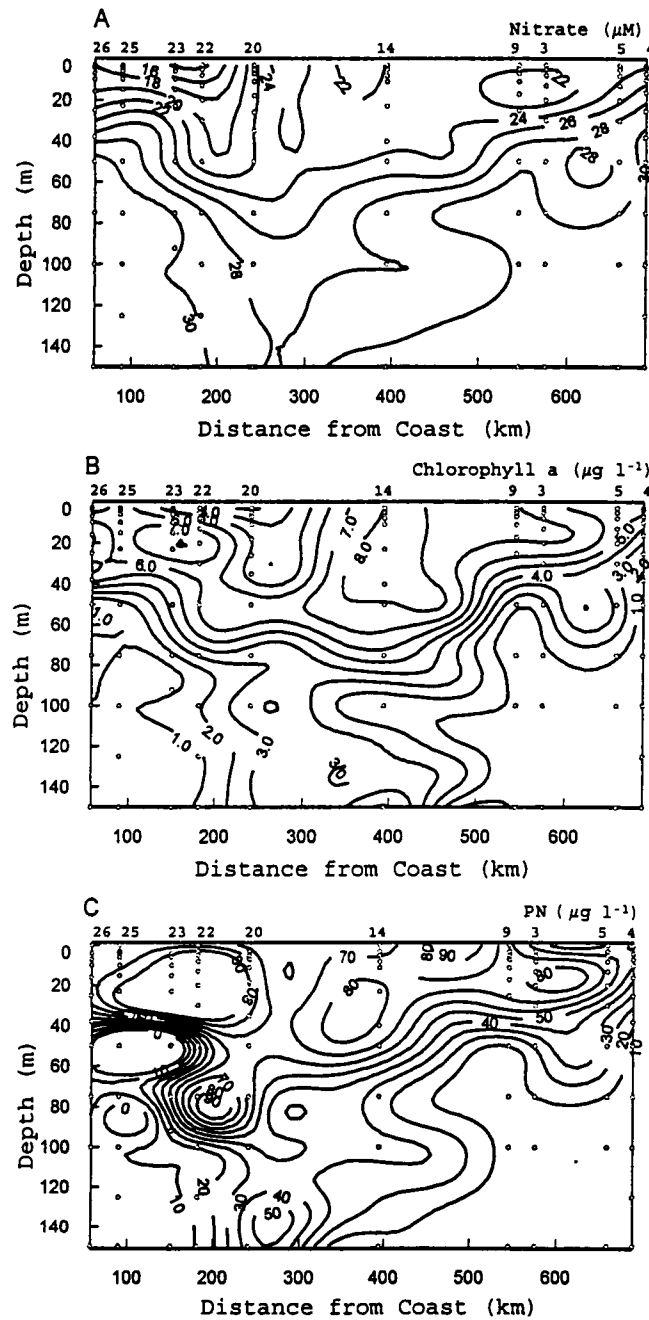


Figure 18. Distribution of nitrate, chlorophyll, and particulate nitrogen within transect 1 of RSP²-95.

Transect 2

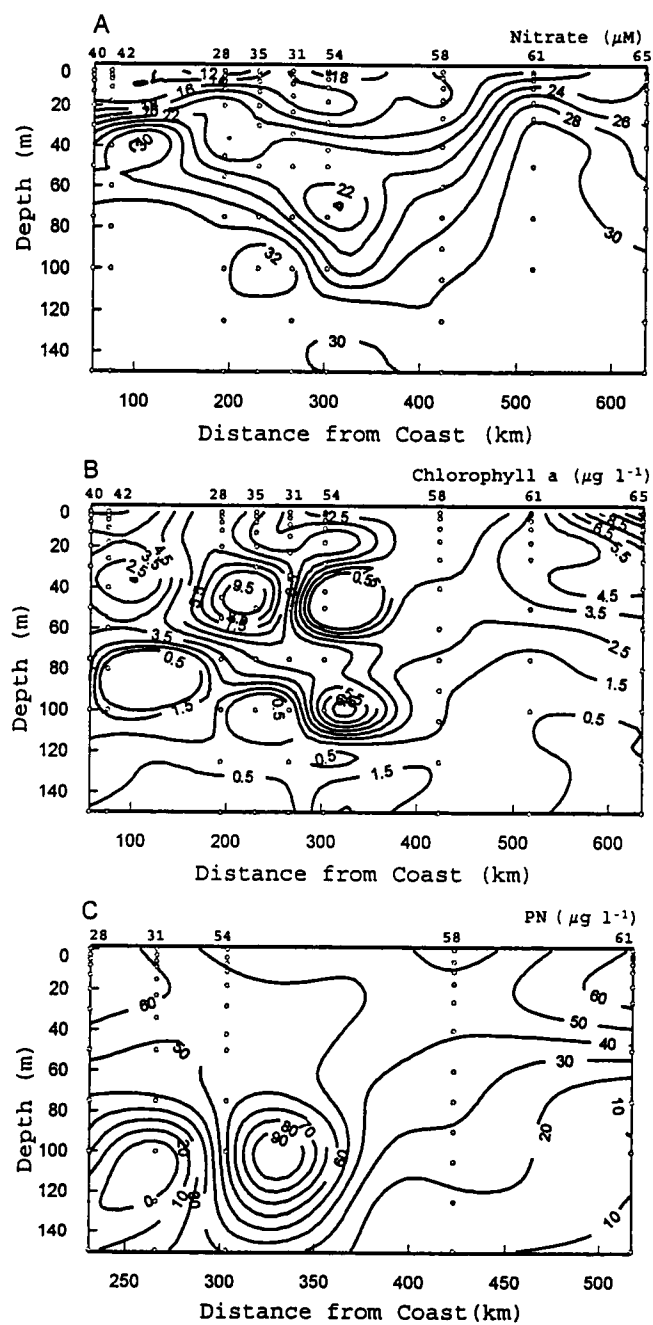


Figure 19. Distribution of nitrate, chlorophyll, and particulate nitrogen within transect 2 of RSP²-95.

Transect 3

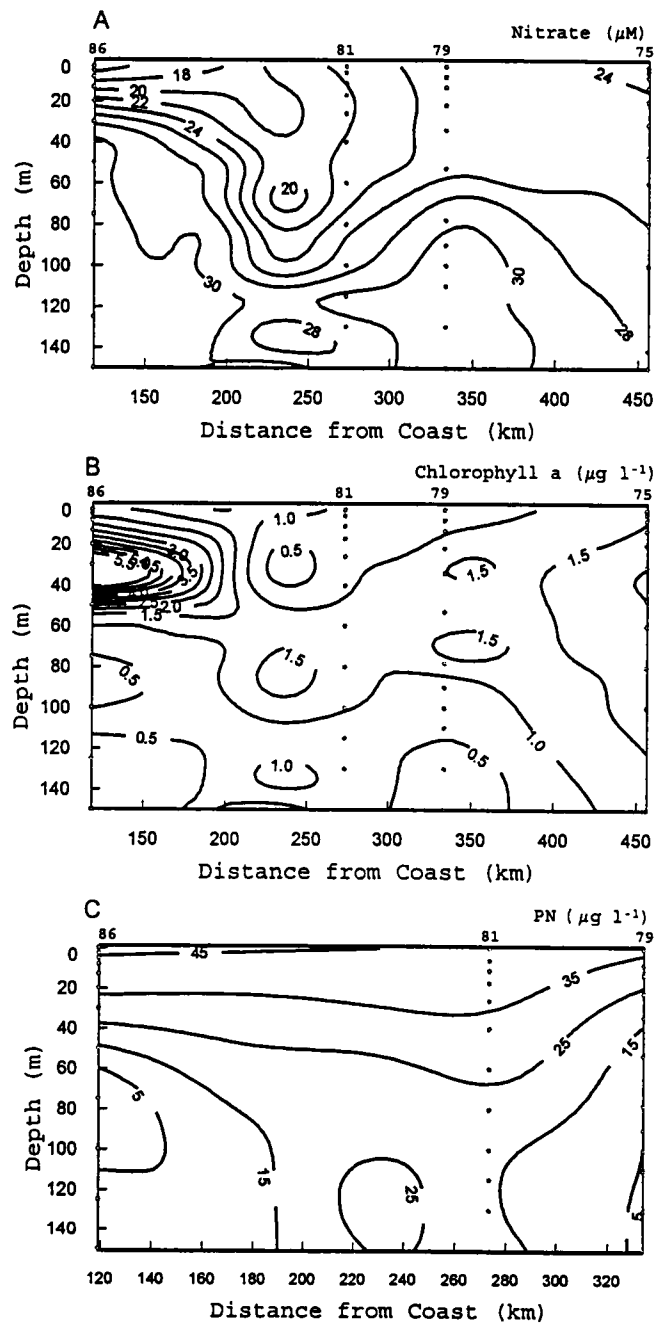


Figure 20. Distribution of nitrate, chlorophyll, and particulate nitrogen within transect 3 of RSP²-95.

lowest nitrate concentration was observed at Station 22, and the highest nitrate concentration was observed at Station 79. Vertical stratification of nitrate concentrations was observed at all stations (Figure 18-20, part A; Appendix C-1). Chlorophyll showed similar patterns as nitrate. The highest surface chlorophyll concentration ($12.1 \mu\text{g l}^{-1}$) was found at Station 23, and the lowest chlorophyll concentrations ($0.7 \mu\text{g l}^{-1}$) was observed at Stations 79 (Figures 18 and 20, part B; Appendix C-1). The surface concentrations of particulate nitrogen ranged from 9.5 to $146.2 \mu\text{g l}^{-1}$ (Figures 18-20; Part C). The lowest surface particulate nitrogen concentration was found at Station 79, and the highest surface particulate nitrogen concentration was found at Station 42 (Figures 19 and 20, part C; Appendix C-1).

The relationship between nitrate uptake and irradiance in the field experiments of RSP²-95 can also be described as a strong saturation response (Figure 21-32, Appendix C-2). Specific nitrate uptake rates were very low, ranging from 0.0001 h^{-1} to 0.0004 h^{-1} on transect 1, 0.0001 to 0.0002 h^{-1} on transect 2, and 0.0001 to 0.0002 h^{-1} on transect 3 at the lowest irradiance levels. The specific nitrate uptake increased to the maximum rates of 0.0033 to 0.0069 h^{-1} on transect 1, 0.0007 to 0.0056 h^{-1} on transect 2, and 0.0004 to 0.003 h^{-1} on transect 3, at ca. 30 to 50% surface irradiance. Photoinhibition was observed at Stations 3, 5, 9, 14, 22, 25, 26, 28, 31, 35, 40, 42, 54, 58, 61, 79, 81, and 86.

The predicted maximum nitrate uptake rates ranged from 0.0004 h^{-1} to 0.0066 h^{-1} , and were closed to the observed values in the

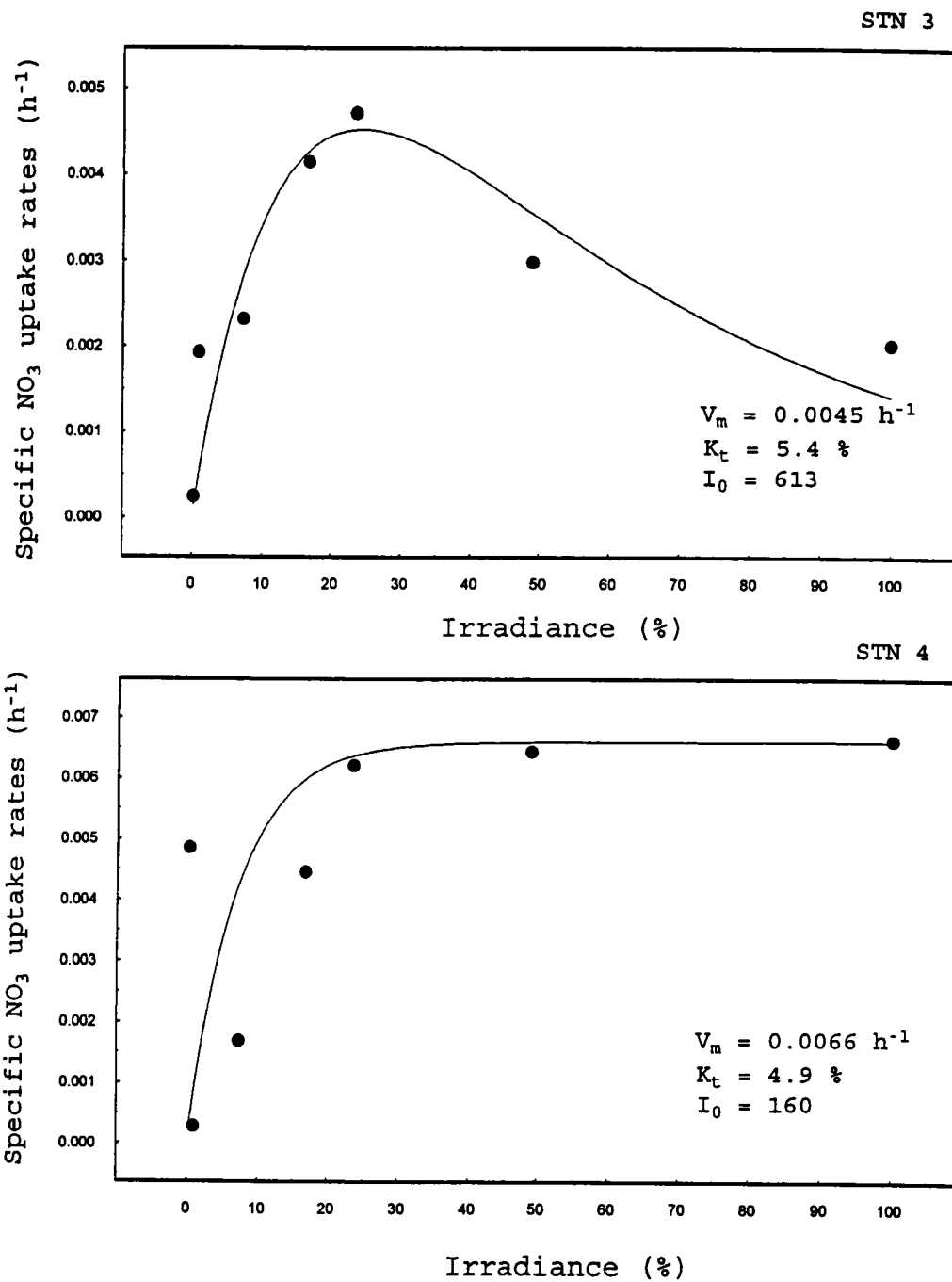


Figure 21. Relationships between specific nitrate uptake and per cent surface irradiance at stations 3 and 4 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

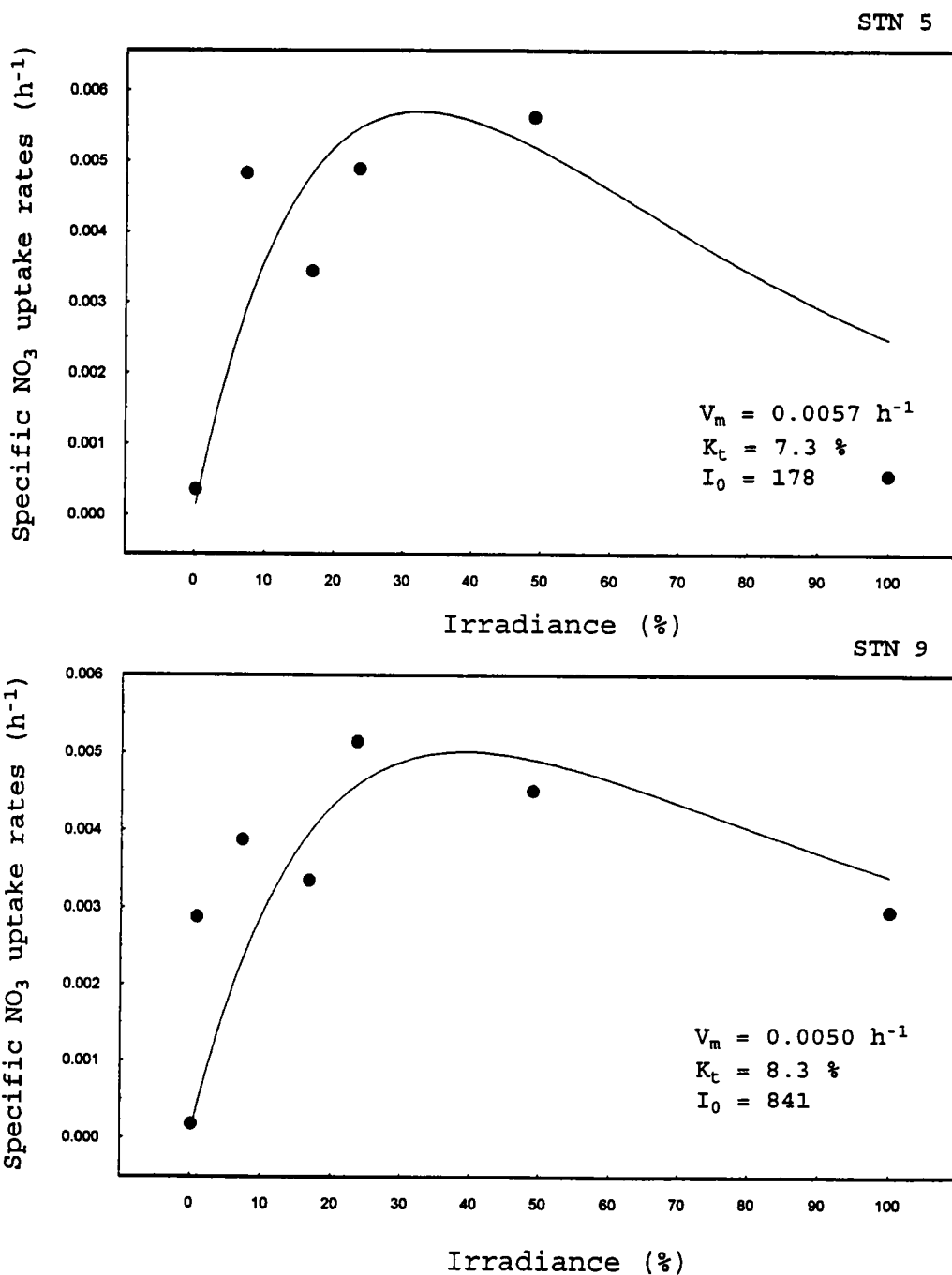


Figure 22. Relationships between specific nitrate uptake and per cent surface irradiance at stations 5 and 9 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

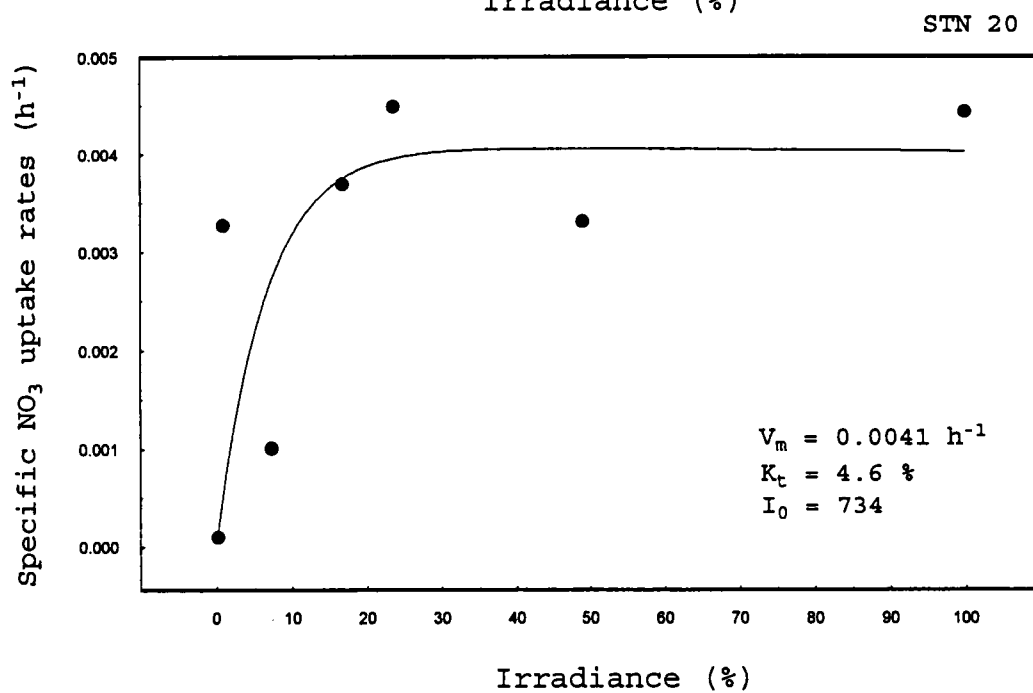
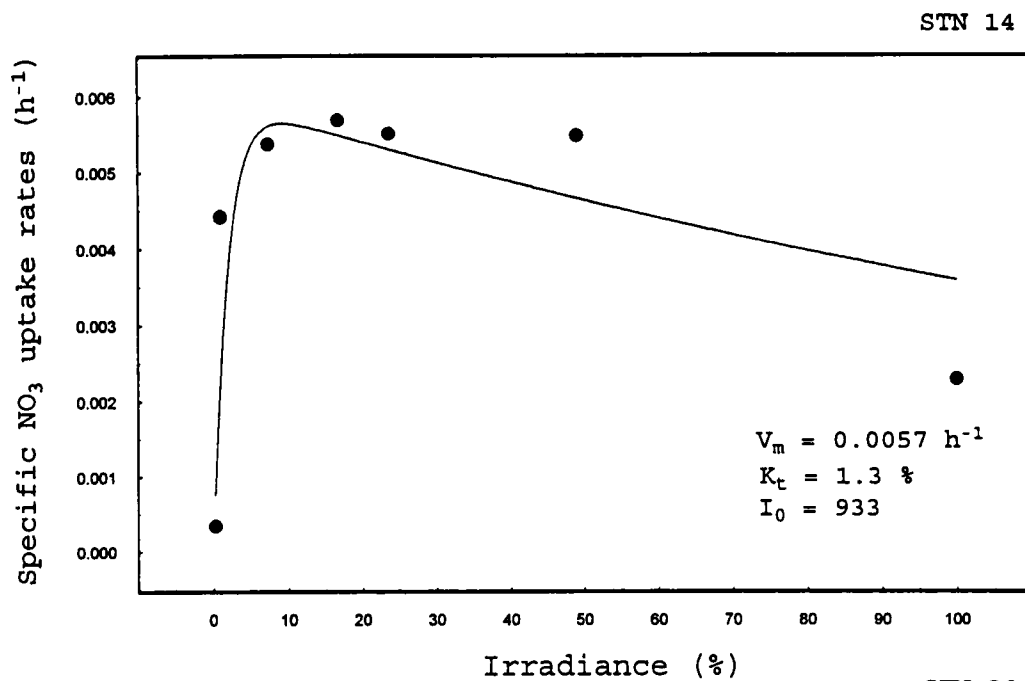


Figure 23. Relationships between specific nitrate uptake and per cent surface irradiance at stations 14 and 20 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

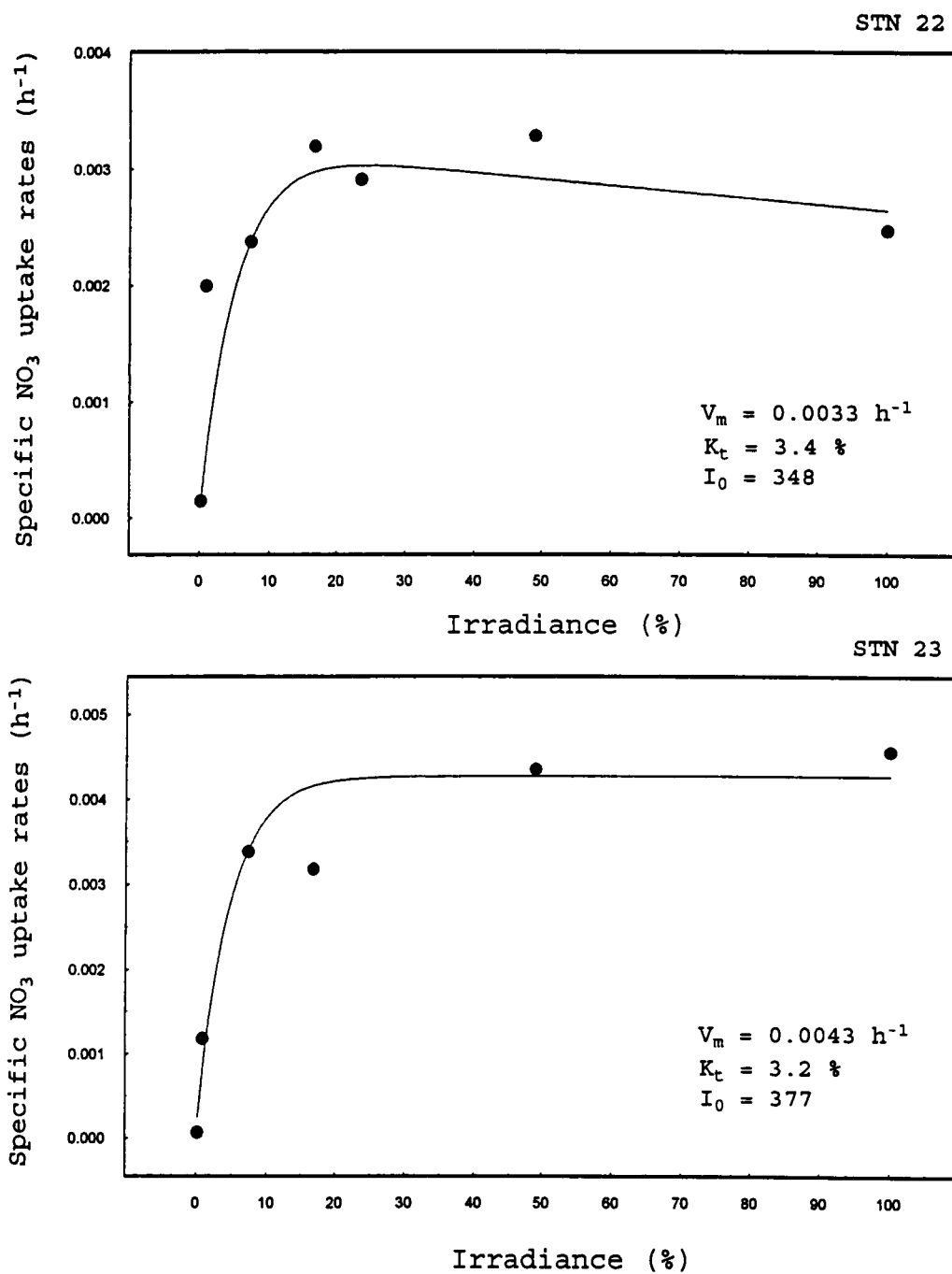


Figure 24. Relationships between specific nitrate uptake and per cent surface irradiance at stations 22 and 23 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

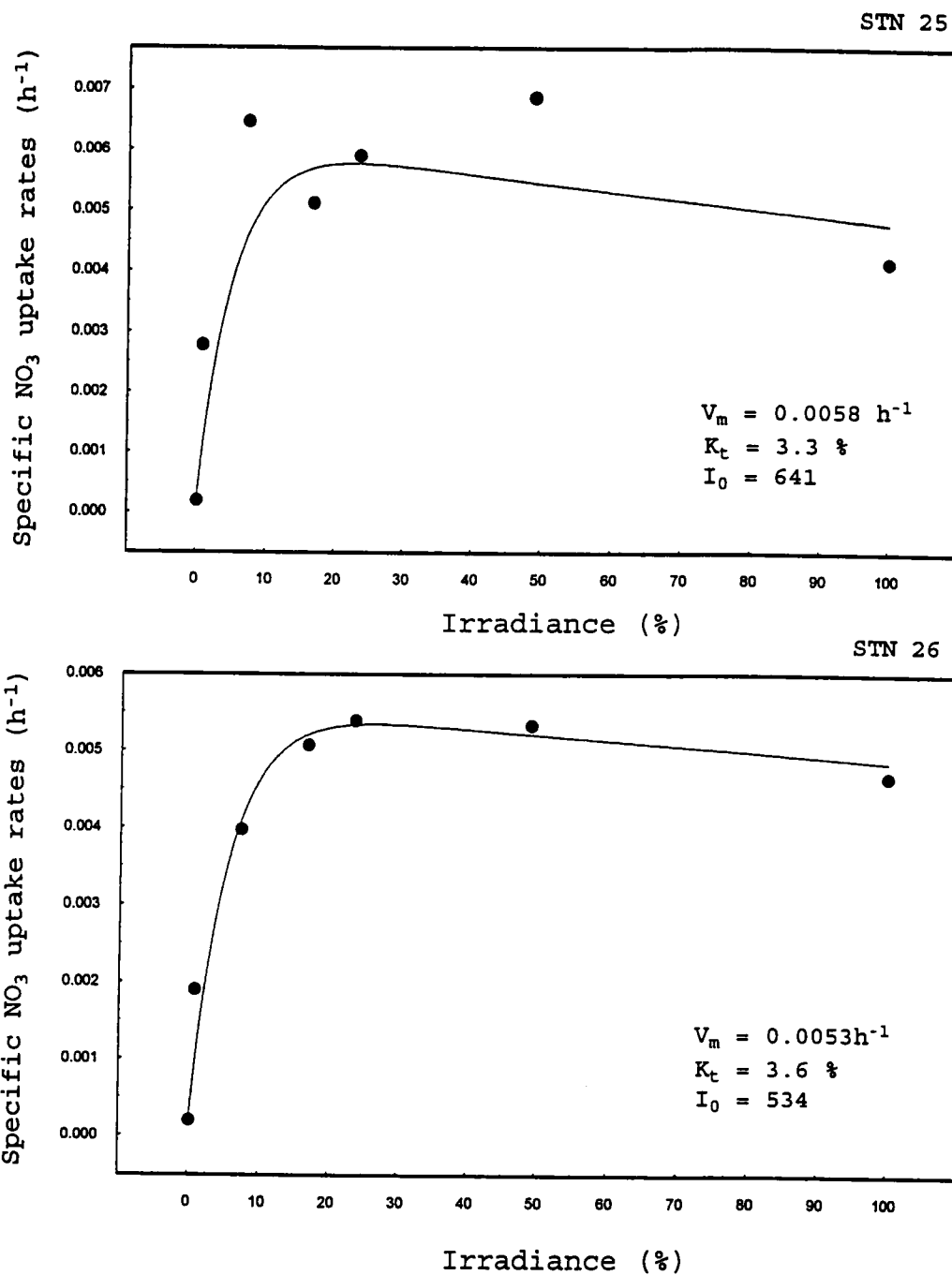


Figure 25. Relationships between specific nitrate uptake and per cent surface irradiance at stations 25 and 26 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

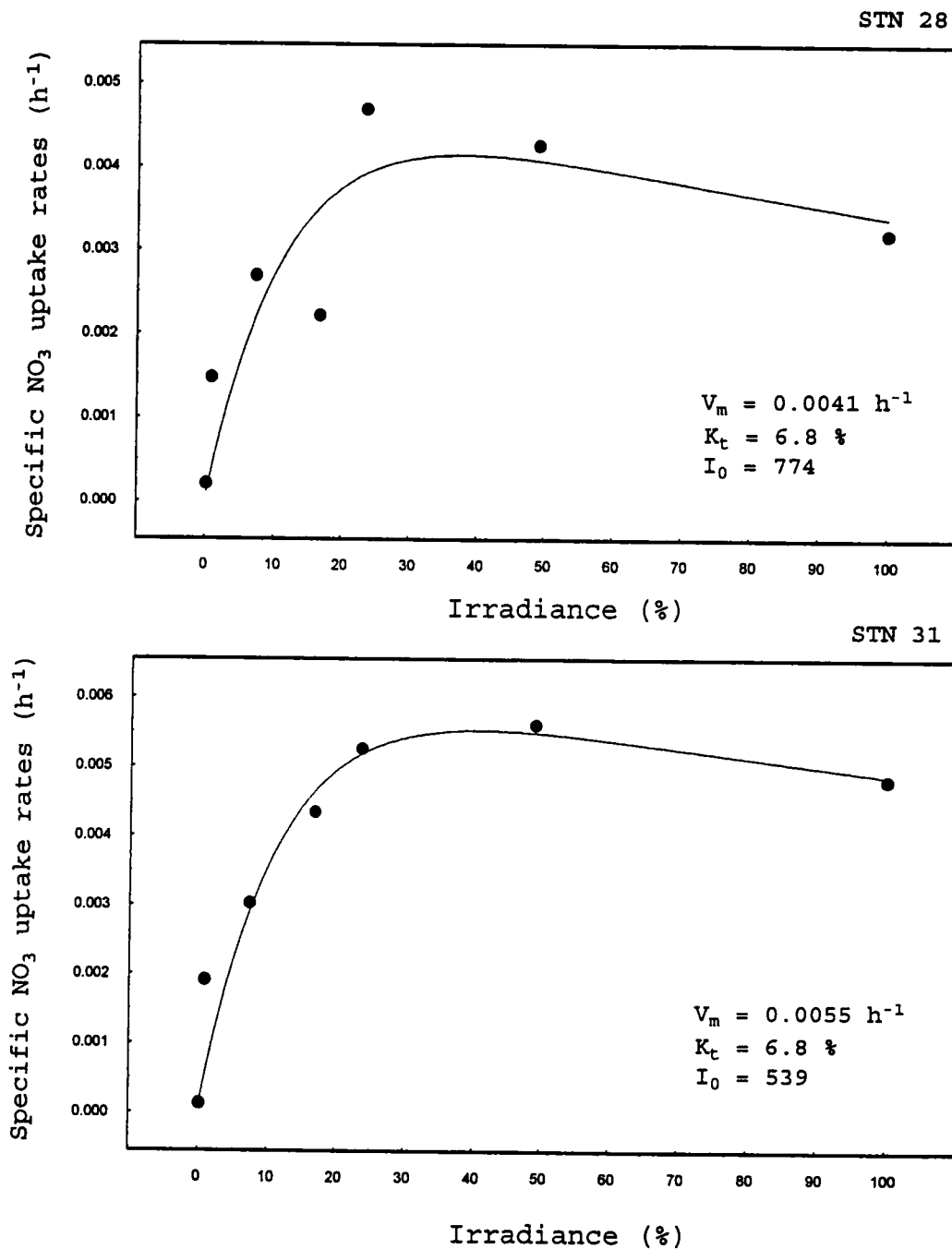


Figure 26. Relationships between specific nitrate uptake and per cent surface irradiance at stations 28 and 31 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

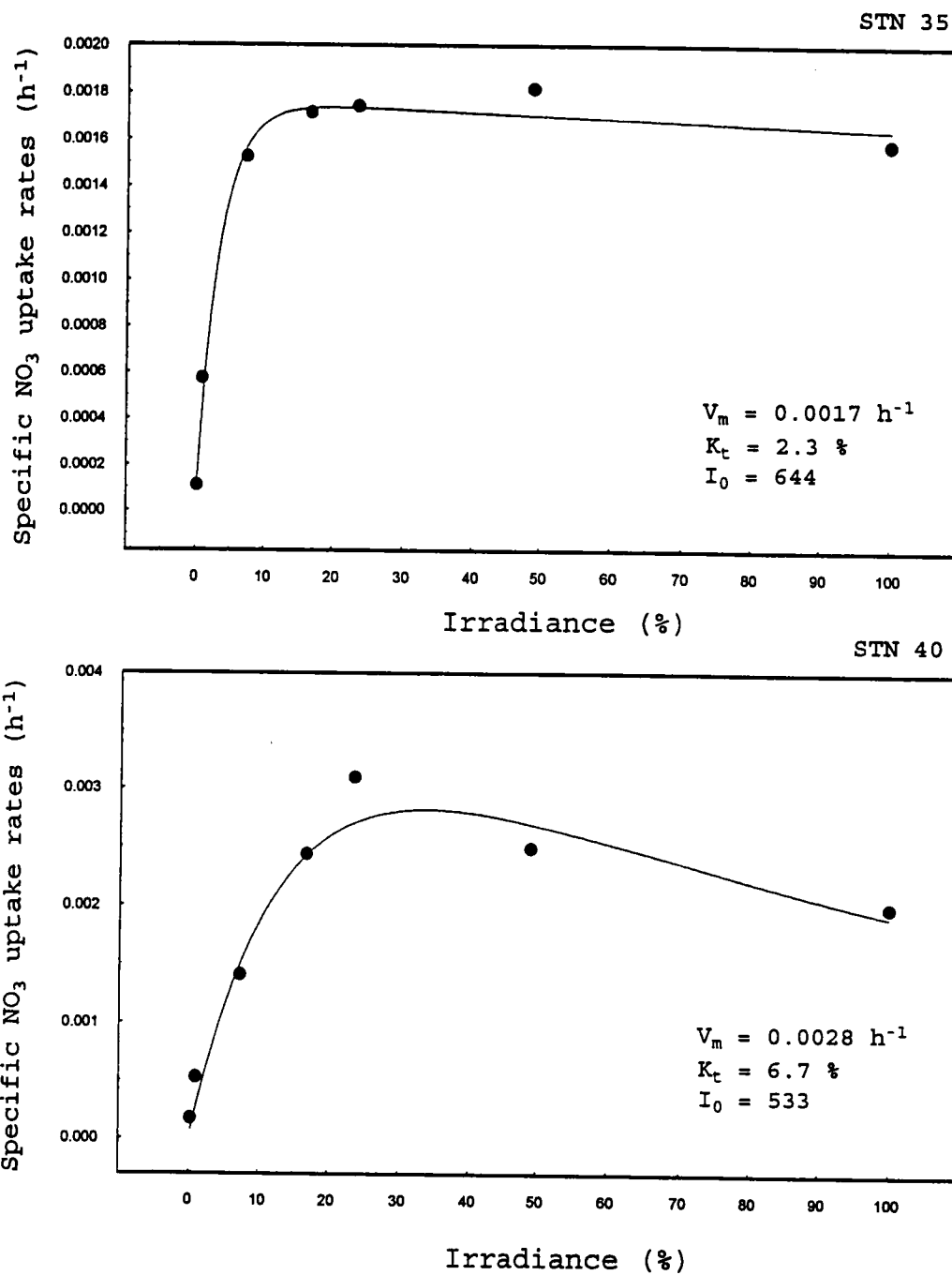


Figure 27. Relationships between specific nitrate uptake and per cent surface irradiance at stations 35 and 40 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

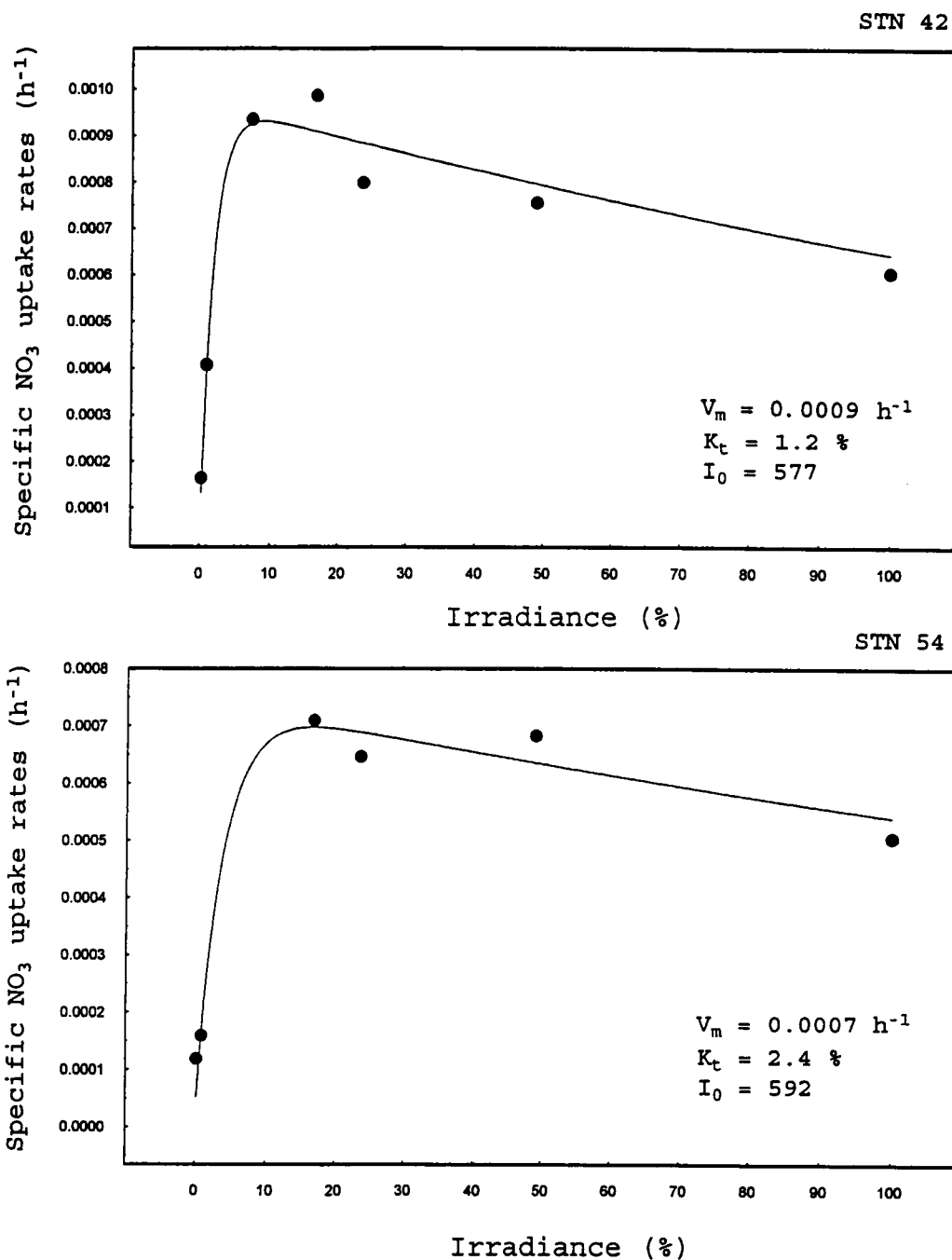


Figure 28. Relationships between specific nitrate uptake and per cent surface irradiance at stations 42 and 54 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

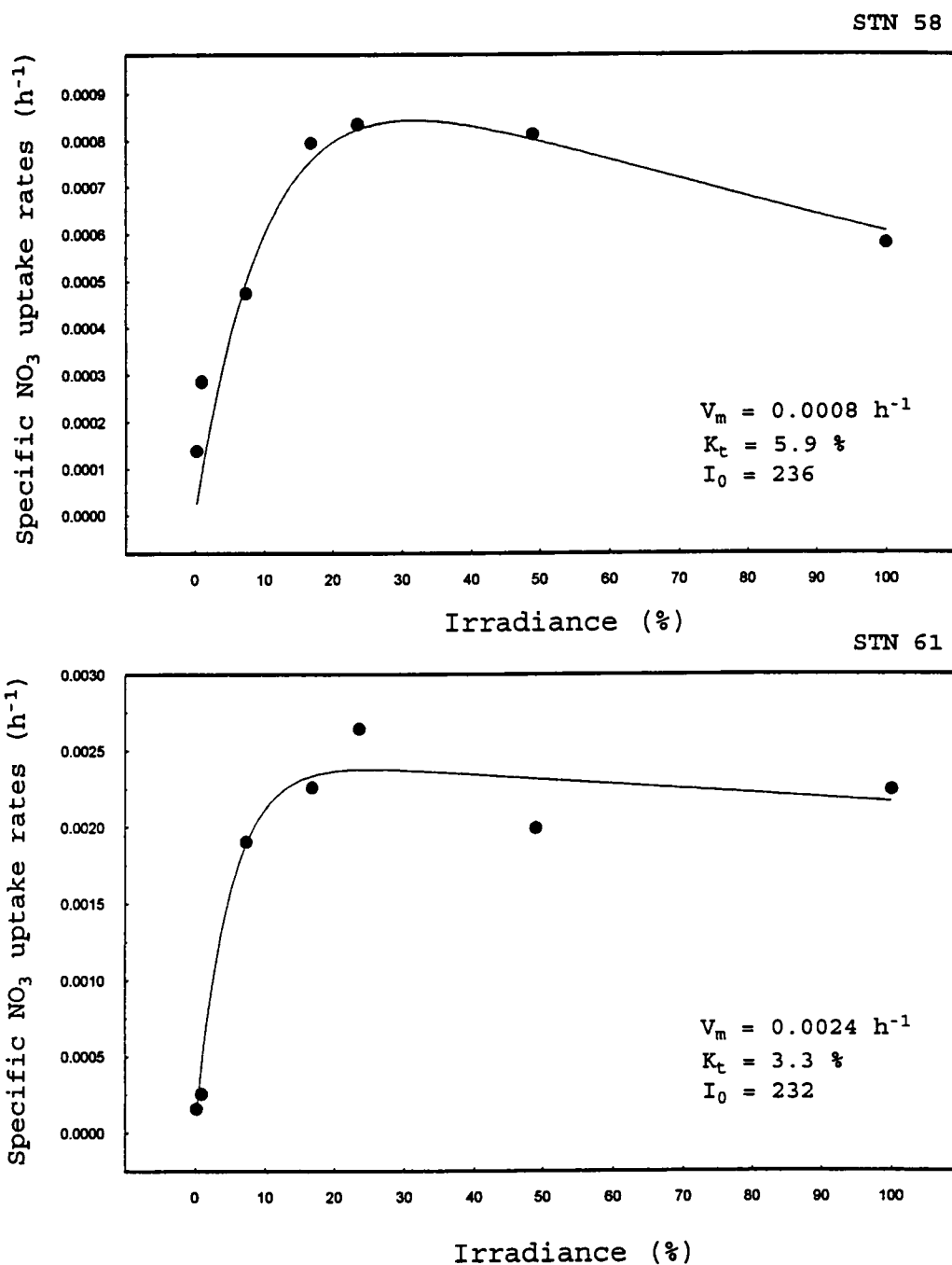


Figure 29. Relationships between specific nitrate uptake and per cent surface irradiance at stations 58 and 61 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

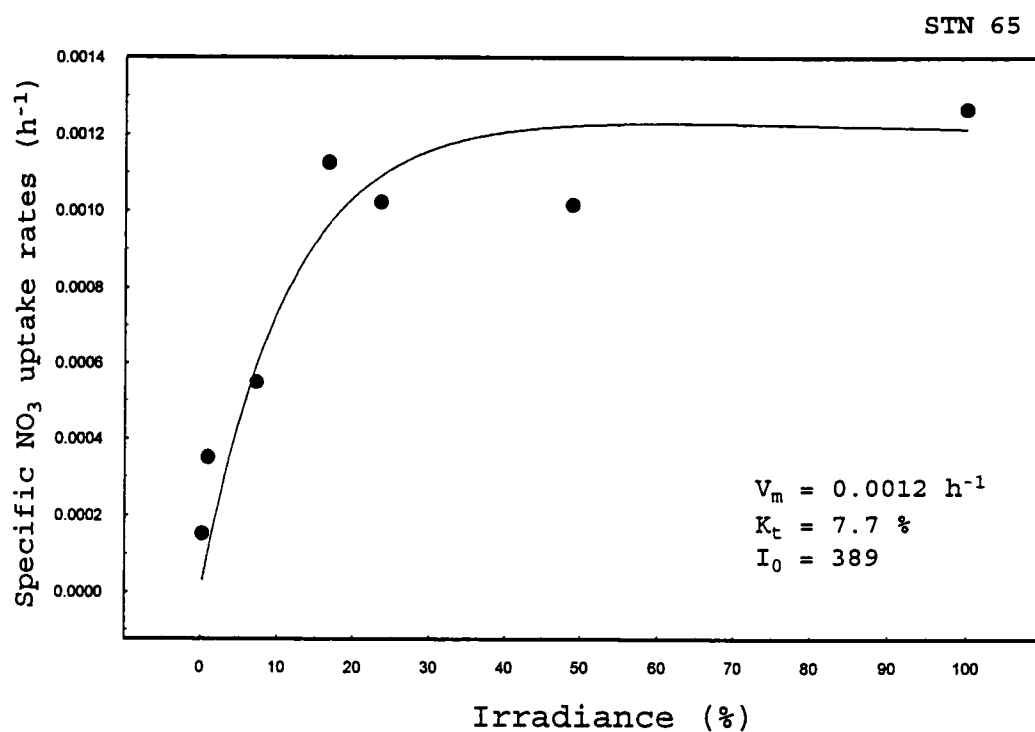


Figure 30. Relationship between specific nitrate uptake and per cent surface irradiance at station 65 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{ s}^{-1}$.

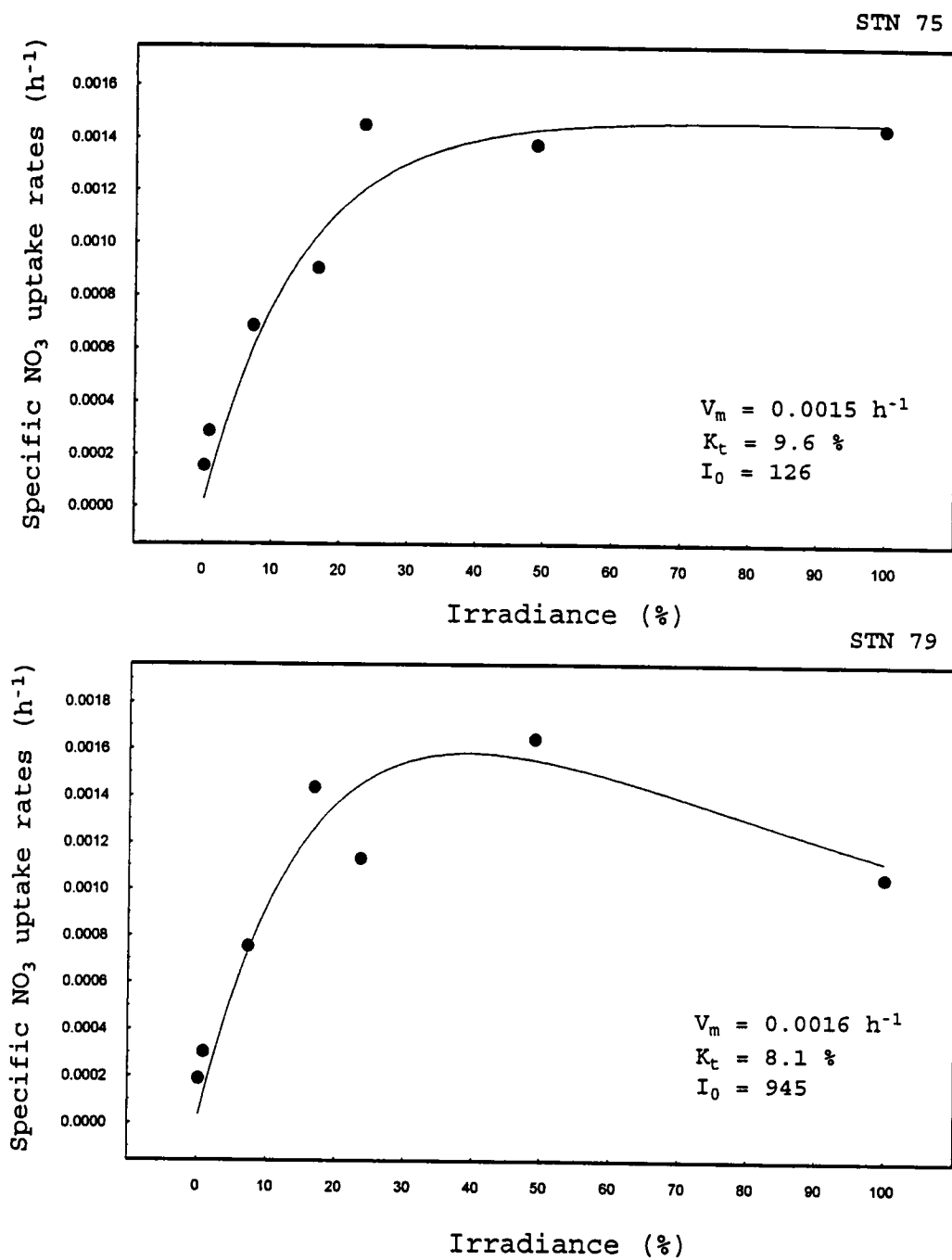


Figure 31. Relationships between specific nitrate uptake and per cent surface irradiance at stations 75 and 79 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

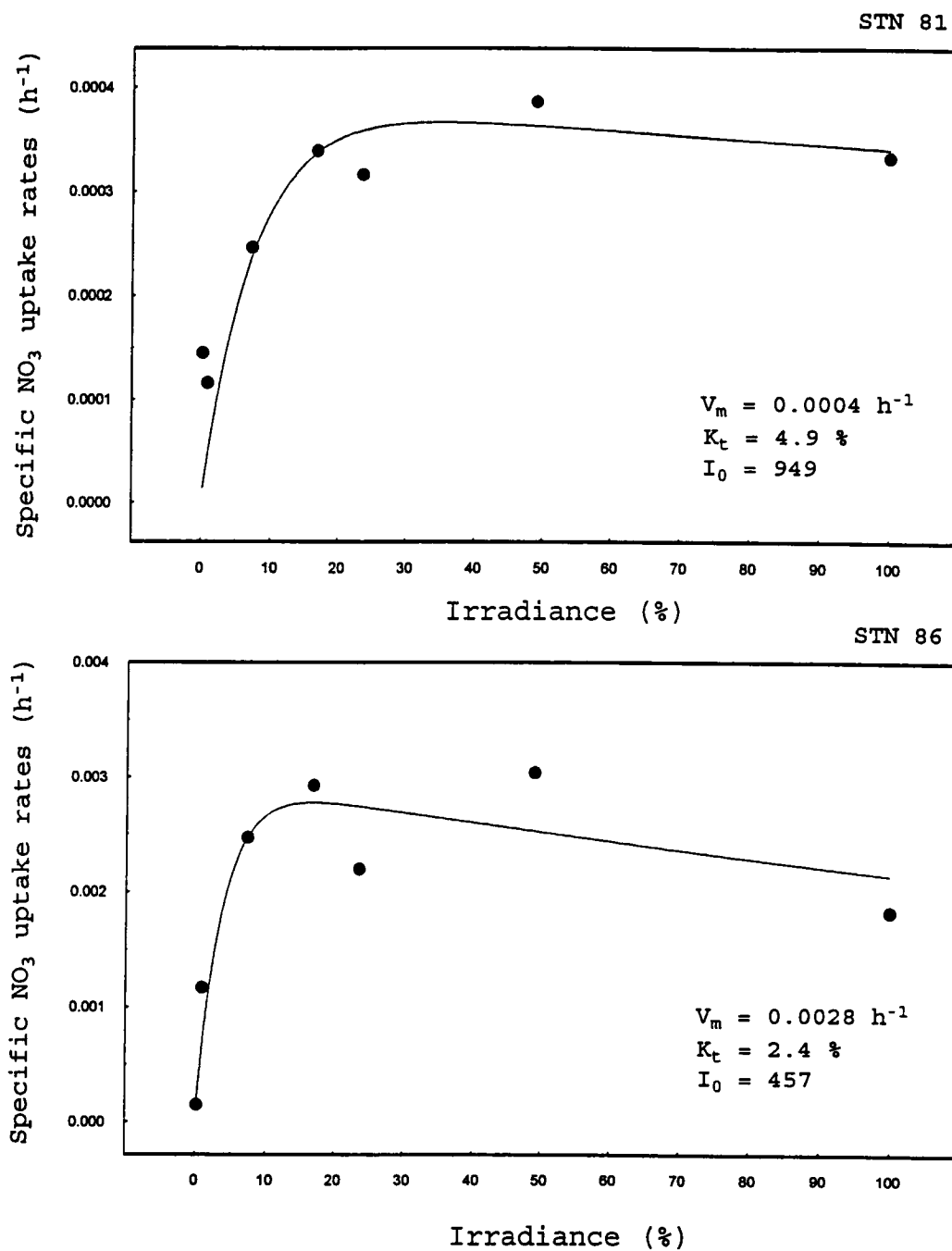


Figure 32. Relationships between specific nitrate uptake and per cent surface irradiance at stations 81 and 86 of RSP²-95. V_m : predicted maximum nitrate uptake rate, K_t : half saturation constant, I_0 : mean surface irradiance during the 24 h incubation, in units of $\mu\text{E m}^{-2} \text{s}^{-1}$.

experiments (Table 4). The optimal irradiance levels for nitrate uptake were from 9 to 80% of surface irradiance (57 to $329 \mu\text{E m}^{-2} \text{s}^{-1}$), and the half-saturation constants were from 1.2 to 9.6% of surface irradiance, in the range of 7.6 to $69 \mu\text{E m}^{-2} \text{s}^{-1}$.

Effects of irradiance on DON release

Laboratory experiments

Irradiance vs. dissolved organic nitrogen release experiments were conducted in the laboratory on July 29 and October 14, 1994, in conjunction with nitrate uptake experiments (Figures 3-7). Both total DON and LMW DON release rates were very low, ranging from 0.0003 to 0.0006 h^{-1} , and 0.00005 to 0.00029 h^{-1} , respectively, at the lowest irradiance levels in 0.5 - 8 h incubations. The total and LMW DON release rates increased to 0.0006 to 0.0011 h^{-1} and 0.00033 to 0.00045 h^{-1} , respectively, at 100% irradiance (Figures 33-37 and Appendix A-3). Analysis of variances of irradiance vs. DON release rates indicated that there existed significant effects of irradiance on both total and LWM DON release rates (Table 5). Incubation time also affected the total DON release rates significantly, though the effects of incubation time on LMW DON release rates were less significant (Table 5).

Table 4. Summary of parameters for the irradiance vs. nitrate uptake experiments of RSP²-95.

Station No.	V_g (h ⁻¹)	α	β	V_m (h ⁻¹)	I_m (%)	$(\mu E\ m^{-2}\ s^{-1})$	(%)	K_t ($\mu E\ m^{-2}\ s^{-1}$)
3	0.0098	0.000539	0.000190	0.0045	24	150	5.4	32.9
4	0.0066	0.000930	0.000000	0.0066	-	-	4.9	7.8
5	0.0178	0.000497	0.000340	0.0057	32	57	7.3	13.0
9	0.0087	0.000393	0.000080	0.0050	39	329	8.3	69.4
14	0.0060	0.002968	0.000031	0.0057	9	86	1.3	12.1
20	0.0041	0.000613	0.000001	0.0041	-	-	4.6	33.6
22	0.0032	0.000610	0.000006	0.0030	24	84	3.4	11.8
23	0.0043	0.000930	0.000000	0.0043	-	-	3.2	12.0
25	0.0062	0.001176	0.000016	0.0058	23	145	3.3	21.4
26	0.0056	0.001025	0.000008	0.0053	26	141	3.6	19.0
28	0.0051	0.000408	0.000020	0.0041	38	293	6.8	52.4
31	0.0064	0.000545	0.000017	0.0055	-	-	6.8	36.8
35	0.0018	0.000529	0.000001	0.0017	20	129	2.3	14.6
40	0.0040	0.000274	0.000030	0.0028	34	181	6.7	35.9
42	0.0010	0.000520	0.000004	0.0009	9	53	1.2	7.1
54	0.0007	0.000197	0.000002	0.0007	17	99	2.4	14.2
58	0.0011	0.000096	0.000006	0.0008	32	74	5.9	13.8
61	0.0025	0.000499	0.000003	0.0024	25	58	3.3	7.6
65	0.0013	0.000110	0.000001	0.0012	62	242	7.7	29.9
75	0.0015	0.000104	0.000000	0.0015	80	101	9.6	12.1
79	0.0025	0.000127	0.000020	0.0016	39	372	8.1	76.6
81	0.0004	0.000051	0.000001	0.0004	35	335	4.9	46.7
86	0.0030	0.000776	0.000010	0.0028	17	77	2.4	11.1
Mean	0.0045	0.000605	0.000034	0.0033	31	158	4.9	25.7
Sd.	0.0038	0.000591	0.000077	0.0019	17	102	2.3	19.3

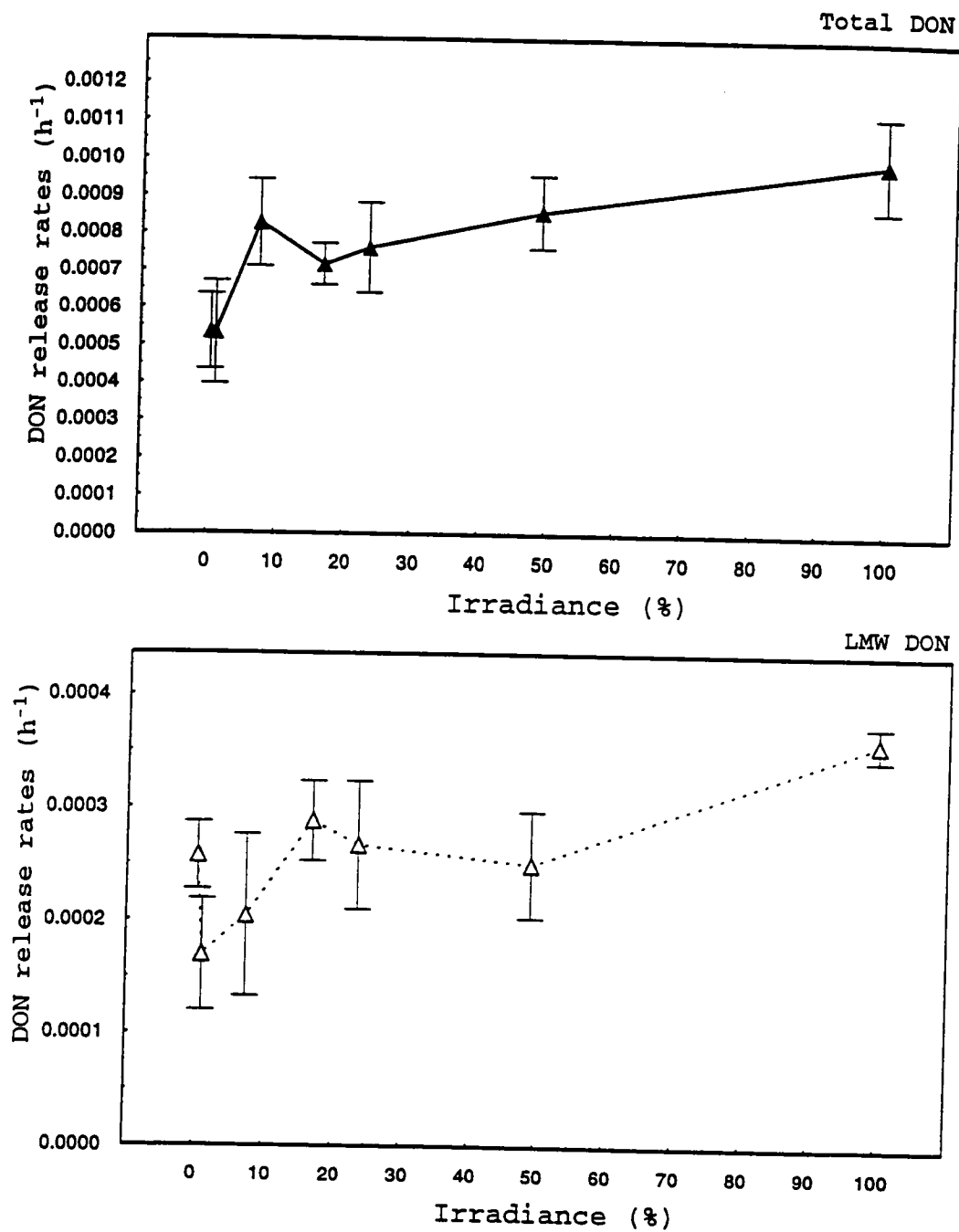


Figure 33. Total and LMW DON release rates vs. per cent surface irradiance for a 0.5 h incubation in the laboratory.

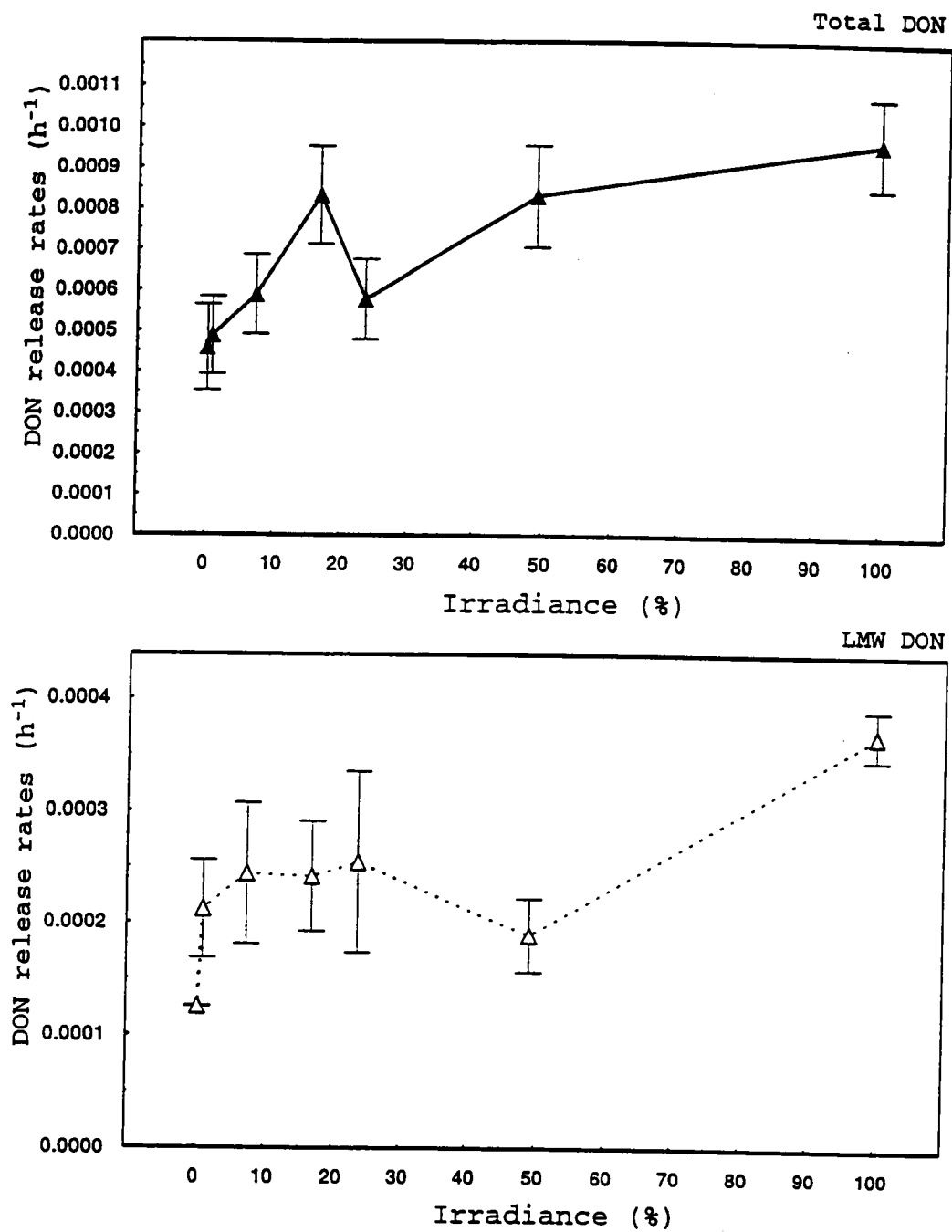


Figure 34. Total and LMW DON release rates vs. per cent surface irradiance for a 1 h incubation in the laboratory.

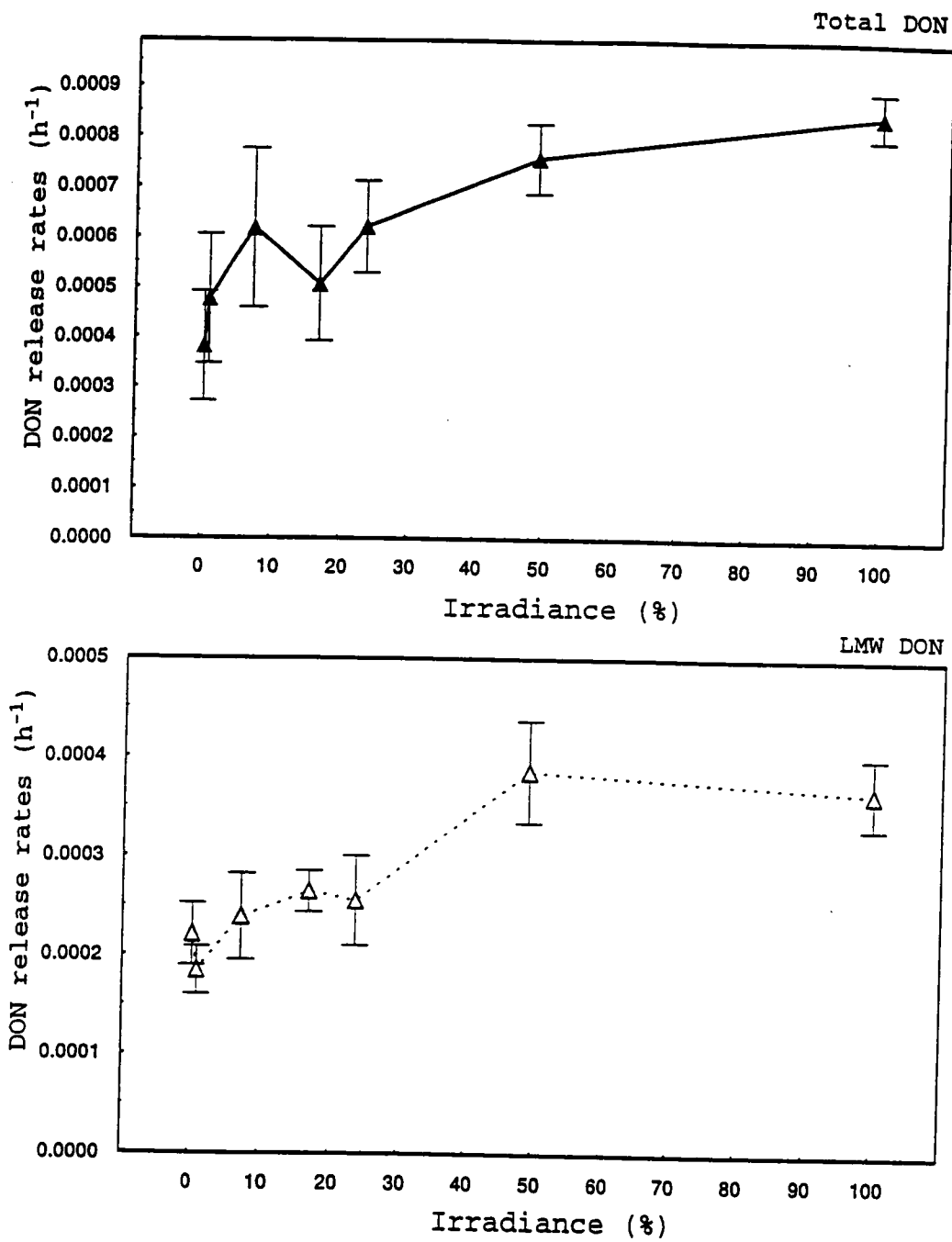


Figure 35. Total and LMW DON release rates vs. per cent surface irradiance for a 3 h incubation in the laboratory.

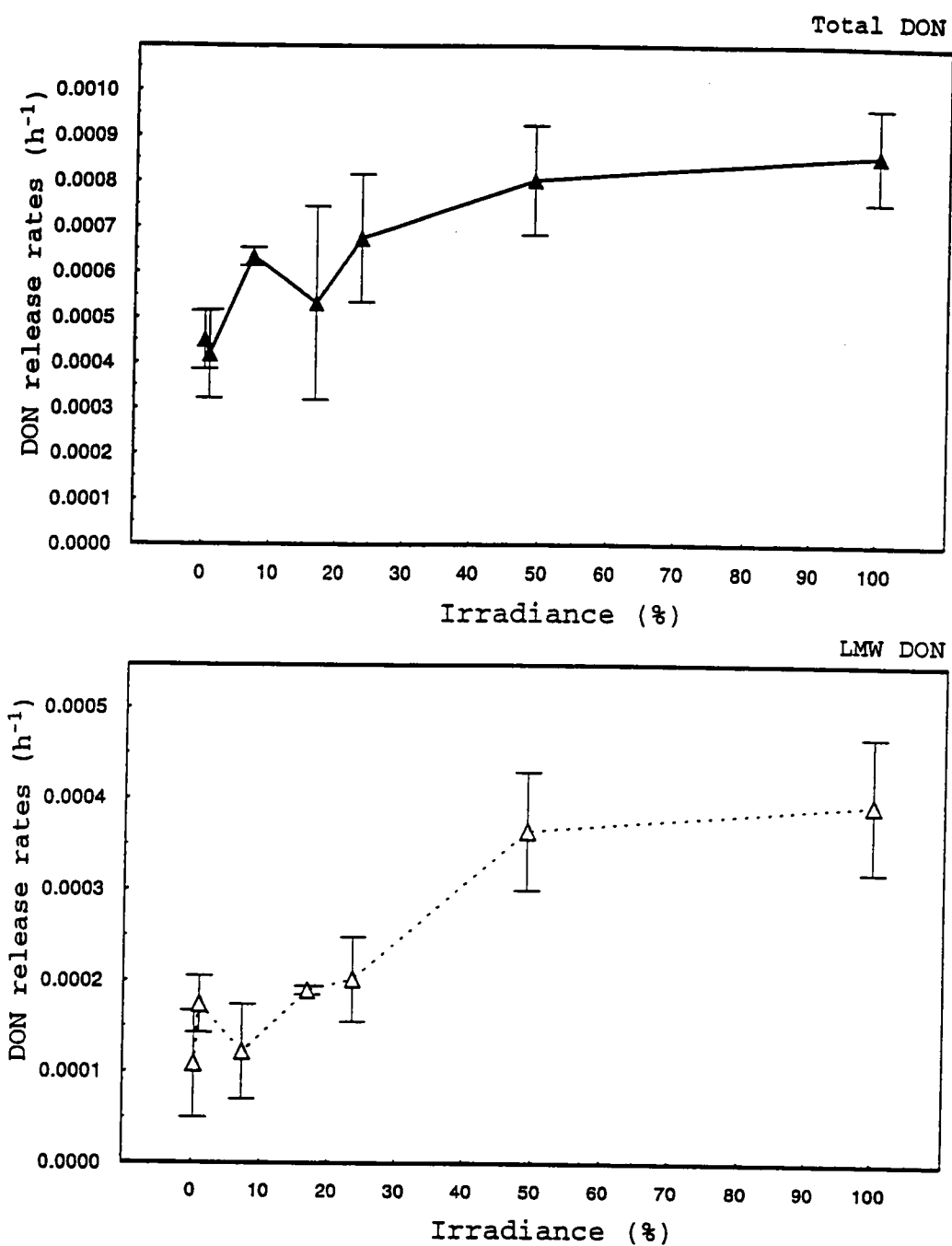


Figure 36. Total and LMW DON release rates vs. per cent surface irradiance for a 5 h incubation in the laboratory.

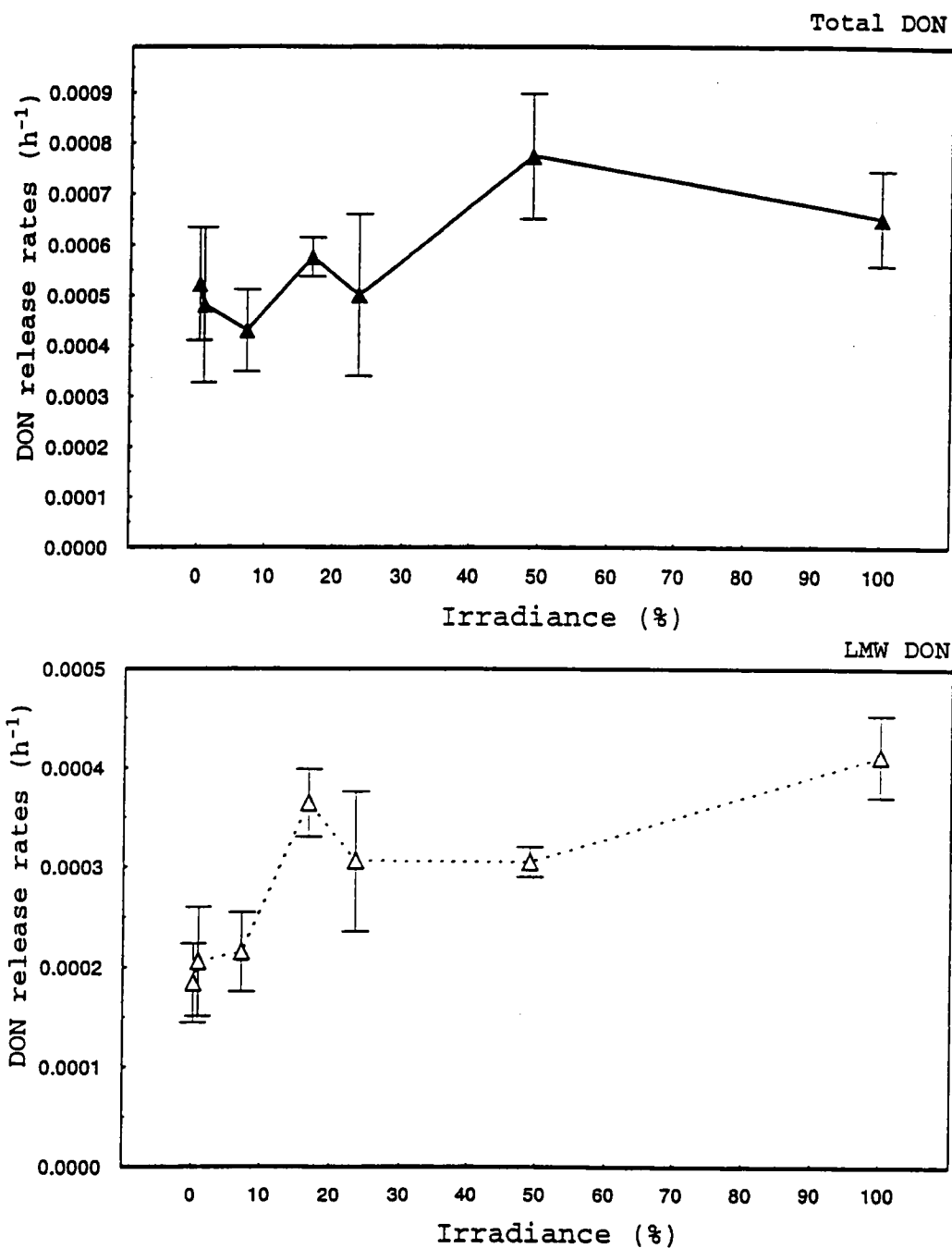


Figure 37. Total and LMW DON release rates vs. per cent surface irradiance for a 8 h incubation in the laboratory.

Table 5. Analysis of variance on the effects of irradiance and incubation time on total and LMW DON release rates in the laboratory experiments.

Source	df	Sum of Squares	Mean Squares	F	p
Total DON					
Incubation Time	4	2.84×10^{-7}	7.11×10^{-8}	3.50	0.0125
Irradiance	6	1.32×10^{-6}	2.20×10^{-7}	10.85	0.0001
Error	59	1.20×10^{-6}	2.03×10^{-8}		
LMW DON					
Incubation Time	4	3.87×10^{-8}	9.68×10^{-9}	2.16	0.0852
Irradiance	6	3.02×10^{-7}	5.03×10^{-8}	11.2	0.0001
Error	59	2.65×10^{-7}	4.49×10^{-9}		

RSP²-94 experiments

The effect of irradiance on total and LMW DON release rates was determined at 14 stations during RSP²-94 (Stations 9, 19, 60, 64, 70, 72, 25, 36, 37, 38, , 47, 53, and 56). Total DON release was similar to that in the laboratory experiments. Most of the lowest total DON release rates were observed at 0.1% irradiance (0.0002 to 0.0010 h⁻¹), and the release rates increased to 0.0006 to 0.0022 h⁻¹ at 100% (Figures 38-44). Analysis of variance on the effects of irradiance on total DON release showed extremely significant effects of irradiance on total DON release rates within Transects 1 and 2 (Tables 6-7), though a less significant effect of irradiance on total DON release for the four stations on Transect 3 was found (Table 8). On the other hand, station location was a factor that affected the total release rates significantly on all transects (Tables 6-8). This indicated that there existed significant spatial and/or temporal variations in total DON release rates during RSP²-94.

LMW DON release rates were very low in RSP²-94, ranging from 0 to 0.00013 h⁻¹, with no obvious spatial and/or temporal patterns (Figures 38-44). Analysis of variance of the irradiance and LWM DON release data from each transect did not indicate any significant effects of irradiance on LWM DON release (Tables 6-8). The station effects on LMW DON release also were not clear. Although a highly significant relationship between station locations and LMW DON release was obtained on Transect 1

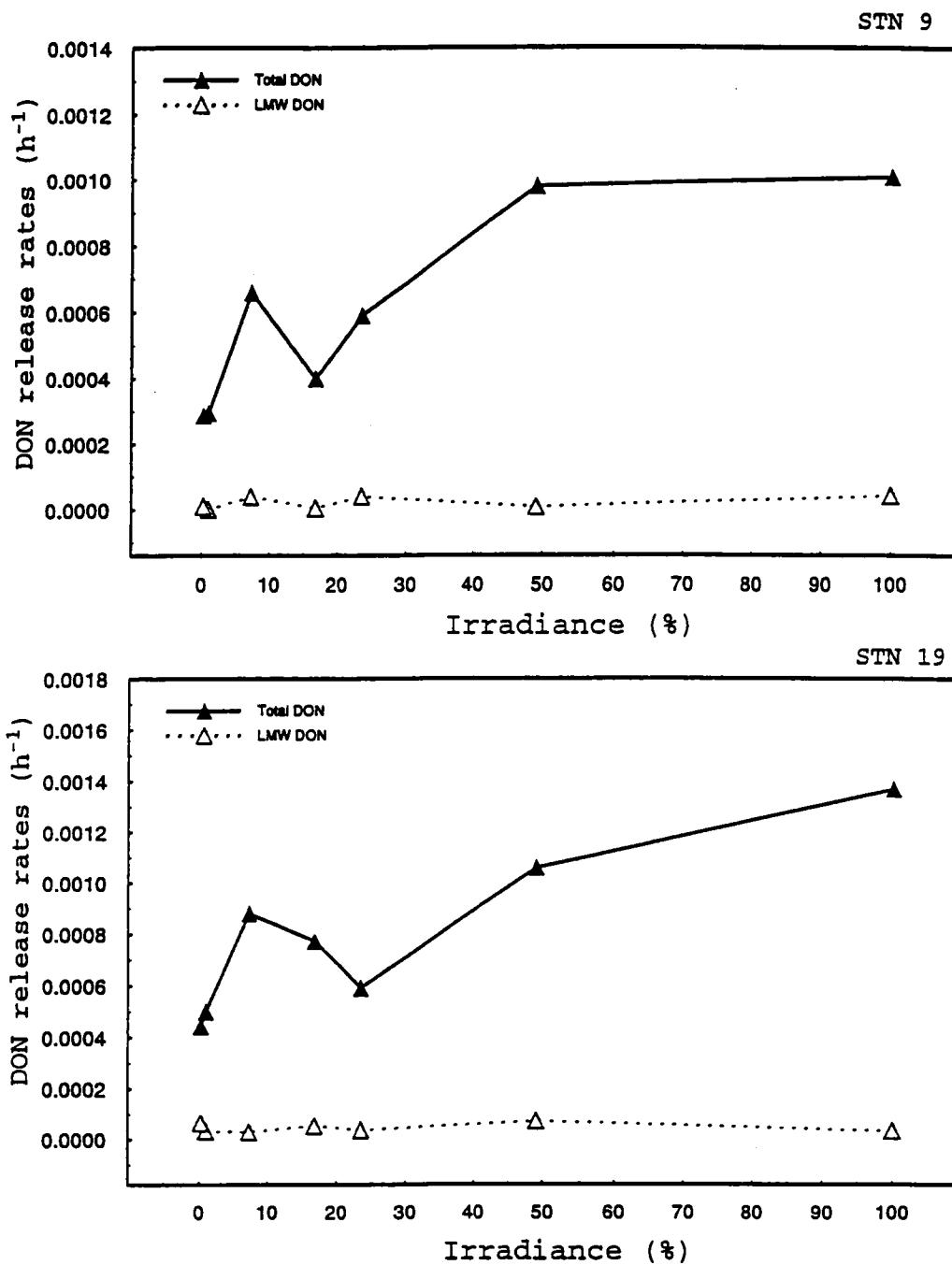


Figure 38. Total and LMW DON release rates vs. per cent surface irradiance at stations 9 and 19 of RSP²-94.

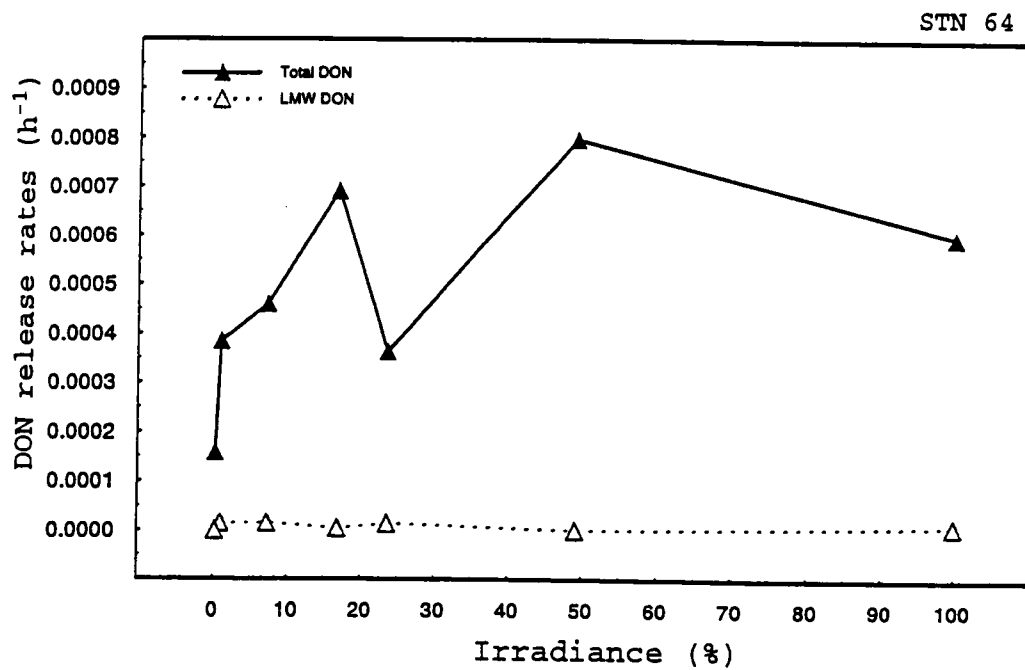
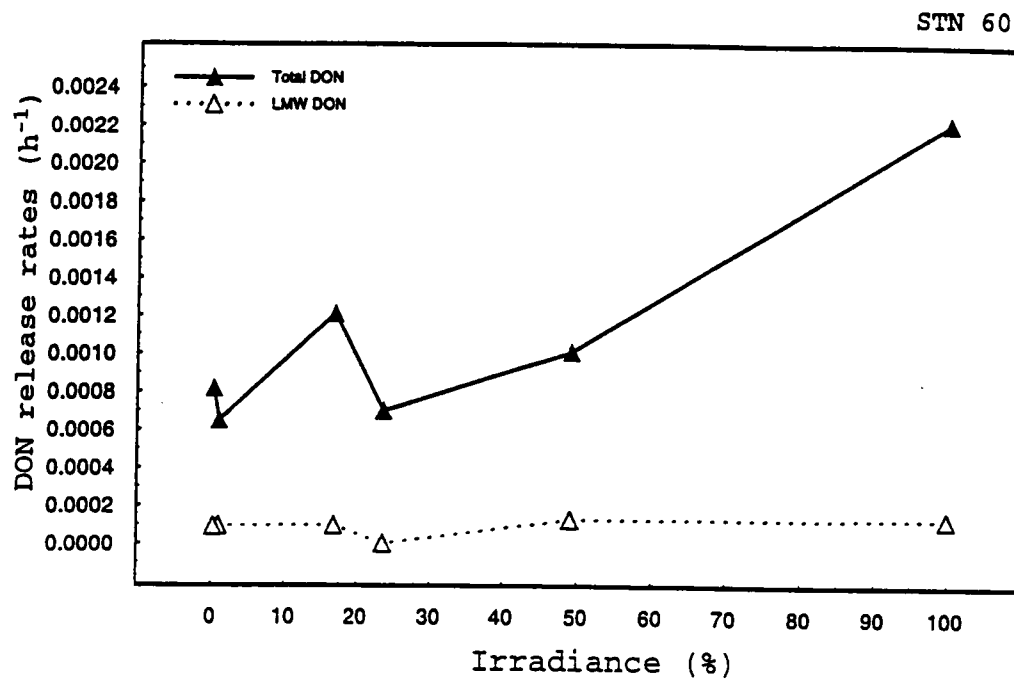


Figure 39. Total and LMW DON release rates vs. per cent surface irradiance at stations 60 and 64 of RSP²-94.

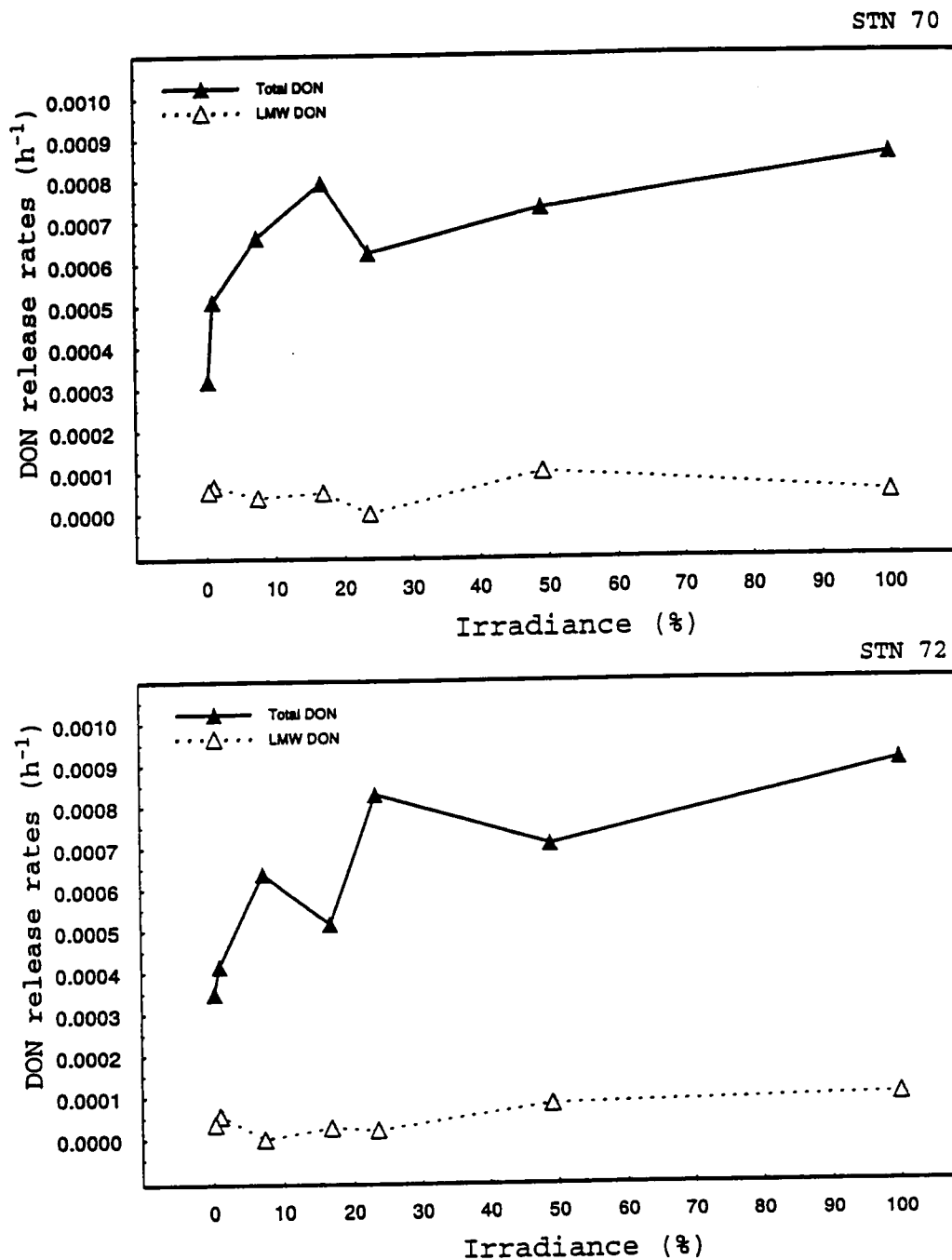
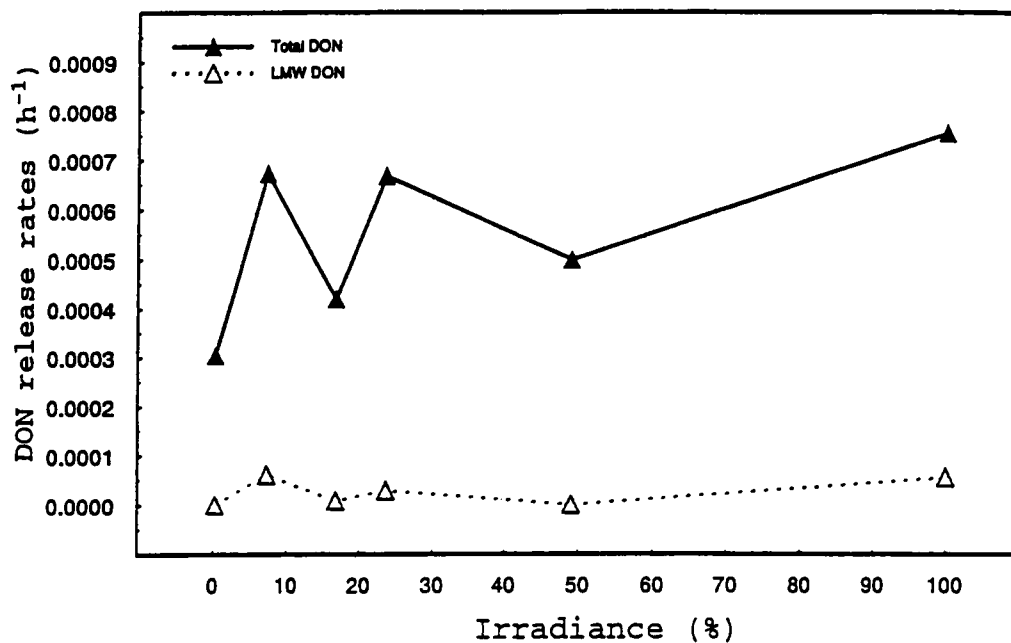


Figure 40. Total and LMW DON release rates vs. per cent surface irradiance at stations 70 and 72 of RSP²-94.

Table 6. Analysis of variance on the effects of irradiance and station on total and LMW DON release rates within transect 1 of RSP²-94.

Source	df	Sum of Squares	Mean Squares	F	p
Total DON					
Station	5	1.46×10^{-6}	2.92×10^{-7}	6.79	0.0003
Irradiance	6	2.42×10^{-6}	4.03×10^{-7}	9.37	0.0001
Error	29	1.25×10^{-6}	4.30×10^{-8}		
LMW DON					
Station	5	2.47×10^{-8}	4.93×10^{-9}	7.29	0.0002
Irradiance	6	8.78×10^{-9}	1.46×10^{-9}	2.16	0.0763
Error	29	1.96×10^{-8}	6.77×10^{-10}		

STN 25



STN 36

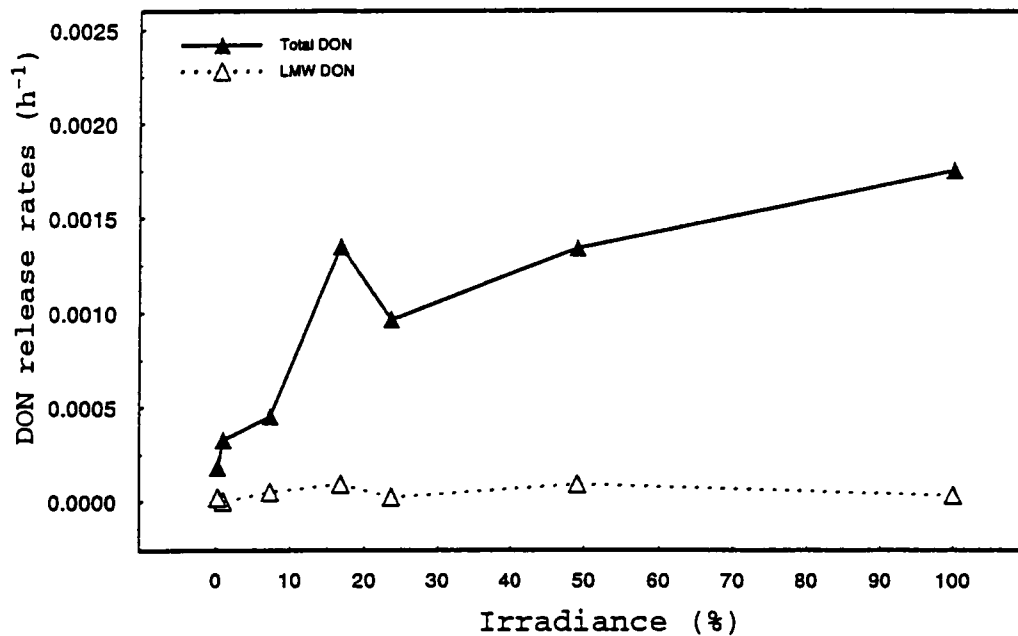


Figure 41. Total and LMW DON release rates vs. per cent surface irradiance at stations 25 and 36 of RSP²-94.

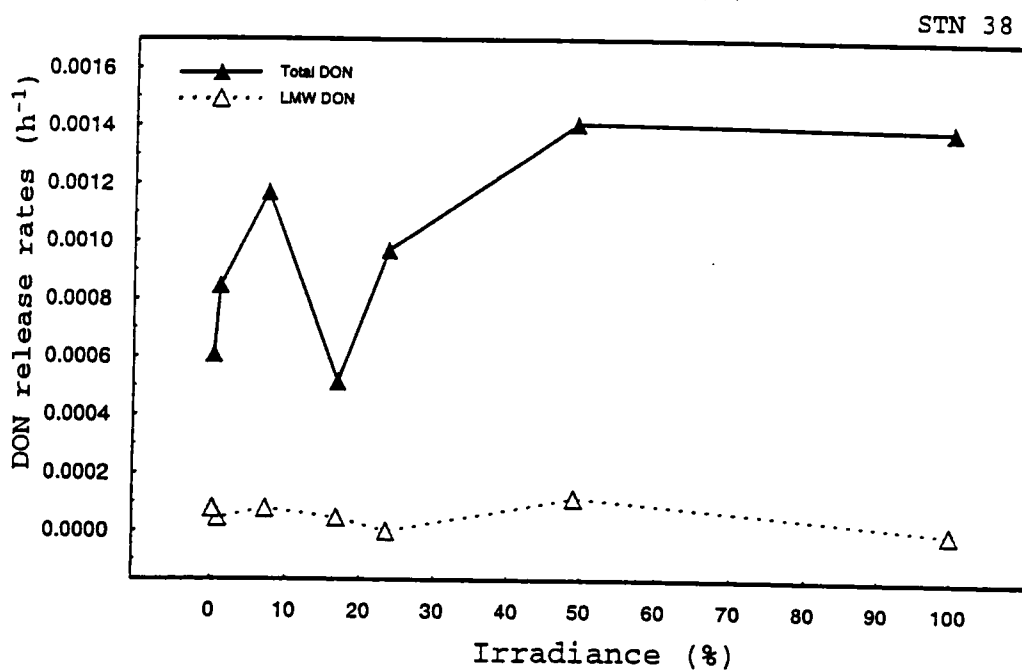
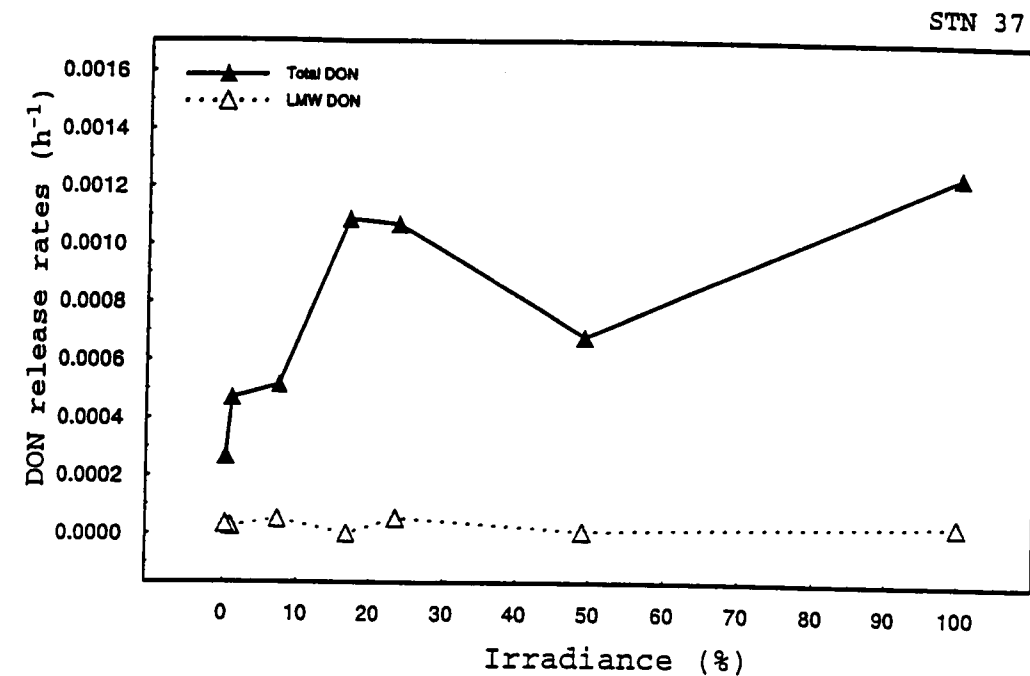
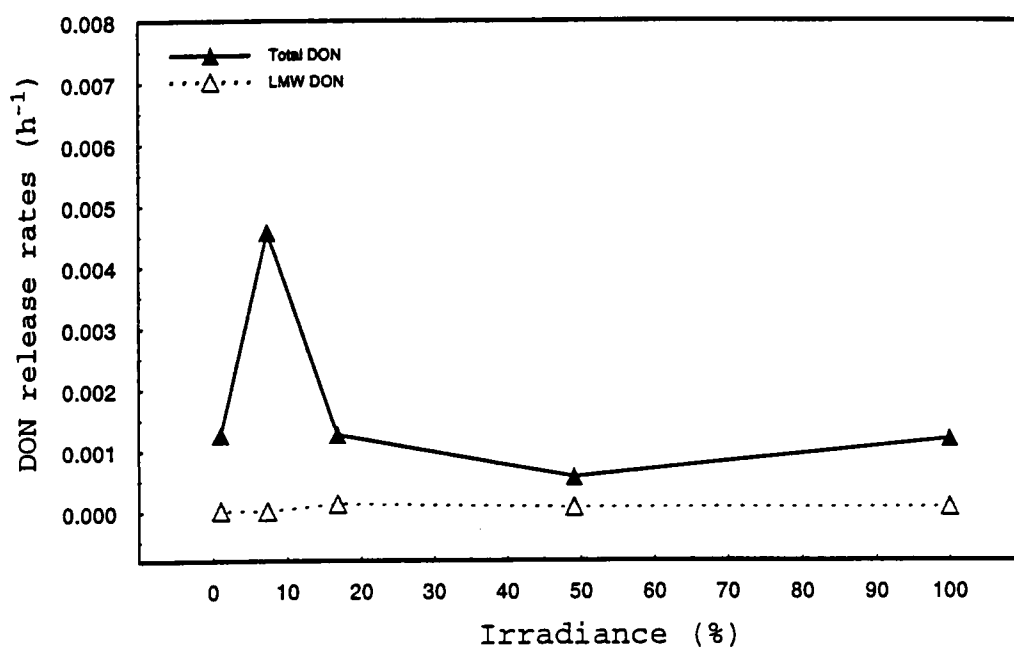


Figure 42. Total and LMW DON release rates vs. per cent surface irradiance at station 37 and 38 of RSP²-94.

Table 7. Analysis of variance on the effects of irradiance and station on total and LMW DON release rates within transect 2 of RSP²-94.

Source	df	Sum of Squares	Mean Squares	F	p
Total DON					
Station	3	8.62×10^{-7}	2.87×10^{-7}	3.18	0.0506
Irradiance	6	2.38×10^{-6}	3.96×10^{-7}	4.39	0.0074
Error	17	1.53×10^{-6}	9.02×10^{-8}		
LMW DON					
Station	3	3.37×10^{-9}	1.12×10^{-9}	0.99	0.4226
Irradiance	6	4.83×10^{-9}	8.06×10^{-10}	0.71	0.6475
Error	26	1.93×10^{-8}	1.13×10^{-9}		

STN 39



STN 47

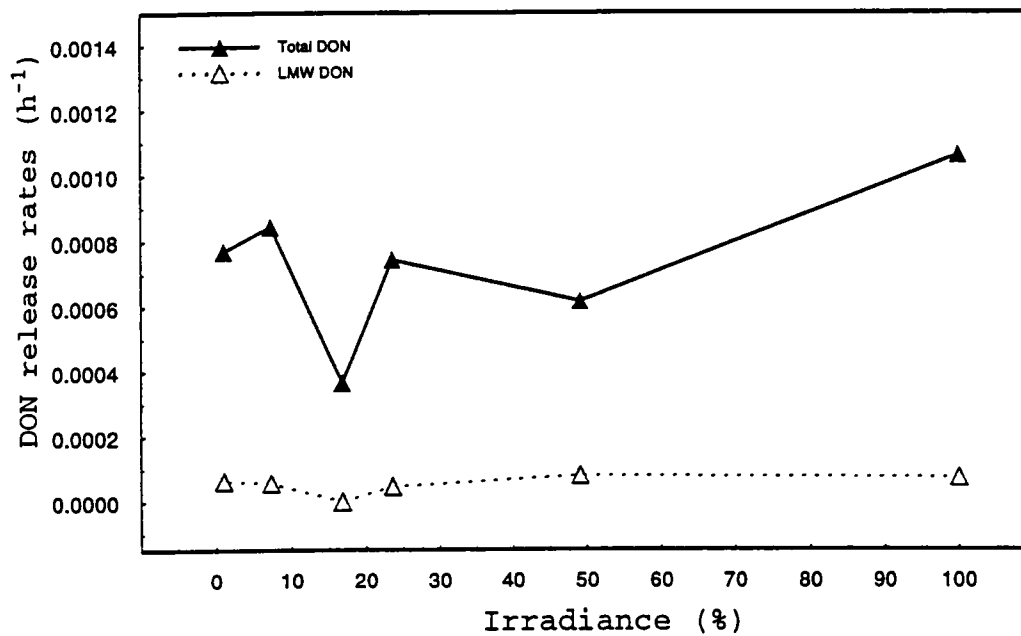
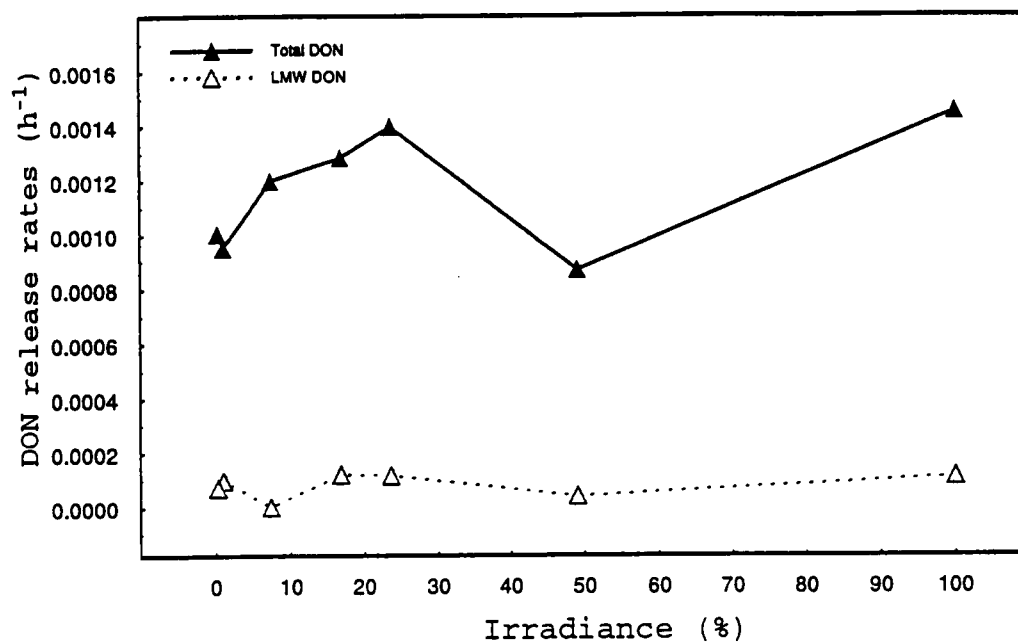


Figure 43. Total and LMW DON release rates vs. per cent surface irradiance at stations 39 and 47 of RSP²-94.

STN 53



STN 56

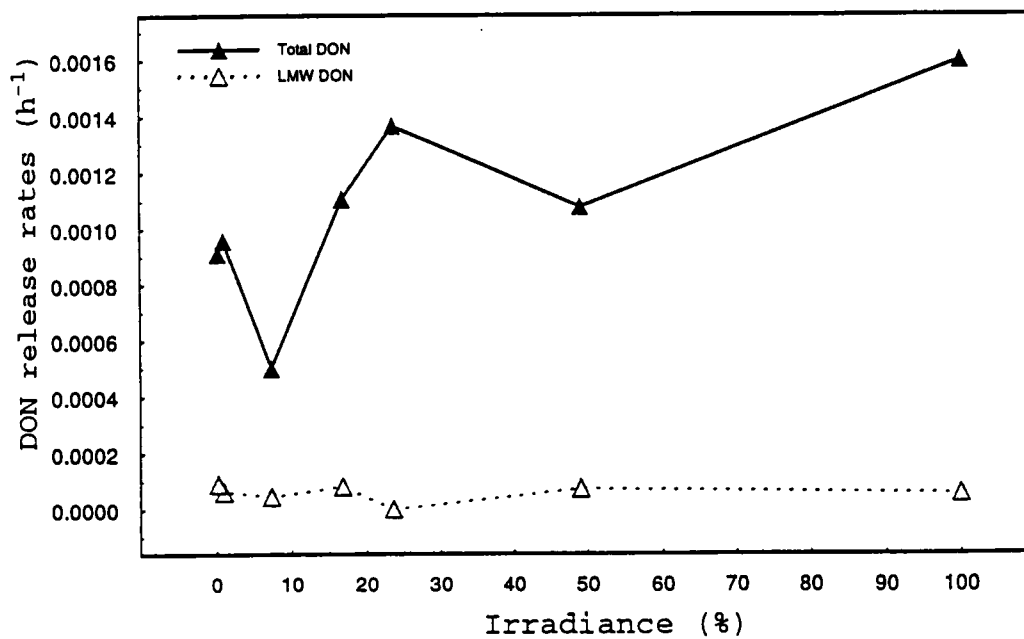


Figure 44. Total and LMW DON release rates vs. per cent surface irradiance at stations 53 and 56 of RSP²-94.

Table 8. Analysis of variance on the effects of irradiance and station on total and LMW DON release rates within transect 3 of RSP²-94.

Source	df	Sum of Square	Mean Square	F	p
Total DON					
Station	2	7.13×10^{-7}	3.56×10^{-7}	6.92	0.0133
Irradiance	6	7.47×10^{-7}	1.24×10^{-7}	2.42	0.0971
Error	11	5.66×10^{-7}	9.02×10^{-8}		
LMW DON					
Station	2	2.25×10^{-9}	1.12×10^{-9}	0.72	0.5103
Irradiance	6	4.23×10^{-9}	7.07×10^{-10}	0.45	0.831
Error	11	1.73×10^{-8}	1.13×10^{-9}		

($p < 0.0005$) (Table 6), analyses for Transects 2 and 3 did not show any significant effects (Tables 7-8).

RSP²-95 experiments

Effects of irradiance on total and LMW DON release rates were determined at 10 stations of RSP²-95 (Stations 3, 5, 14, 20, 22, 26, 54, 61, 75 and 79). The total DON release data from RSP²-95 showed similar patterns to those of RSP²-94, except that the lowest release rates (ca. 0.00001 to 0.0001 h^{-1}) did not always occur at the lowest irradiance (0.1%) as they did at most stations of RSP²-94. In many cases, the lowest total DON release rate occurred at 1-10% irradiance (e.g., Stations 5, 14, and 22; Figures 45-47). For some stations (e.g., Stations 26 and 54; Figures 47, 48) the lowest total DON release rates even occurred at 15-20% irradiance. In contrast, the total DON release rates at high irradiance levels (30-100%) are higher at most stations (0.00003 to 0.00040 h^{-1} ; Figures 45-49). Analysis of variance on the effects of irradiance on total DON release also indicated there existed significant effects of irradiance on the total DON release (Table 9).

Higher percentages of LMW DON release relative to the total DON release rates (ca. 15% on average) were observed in RSP²-95 (Figures 45-49 and Appendix C-4). However, the effects of irradiance on LMW DON release were not clear in RSP²-95. Although the LMW DON release rates were found to increase with irradiance

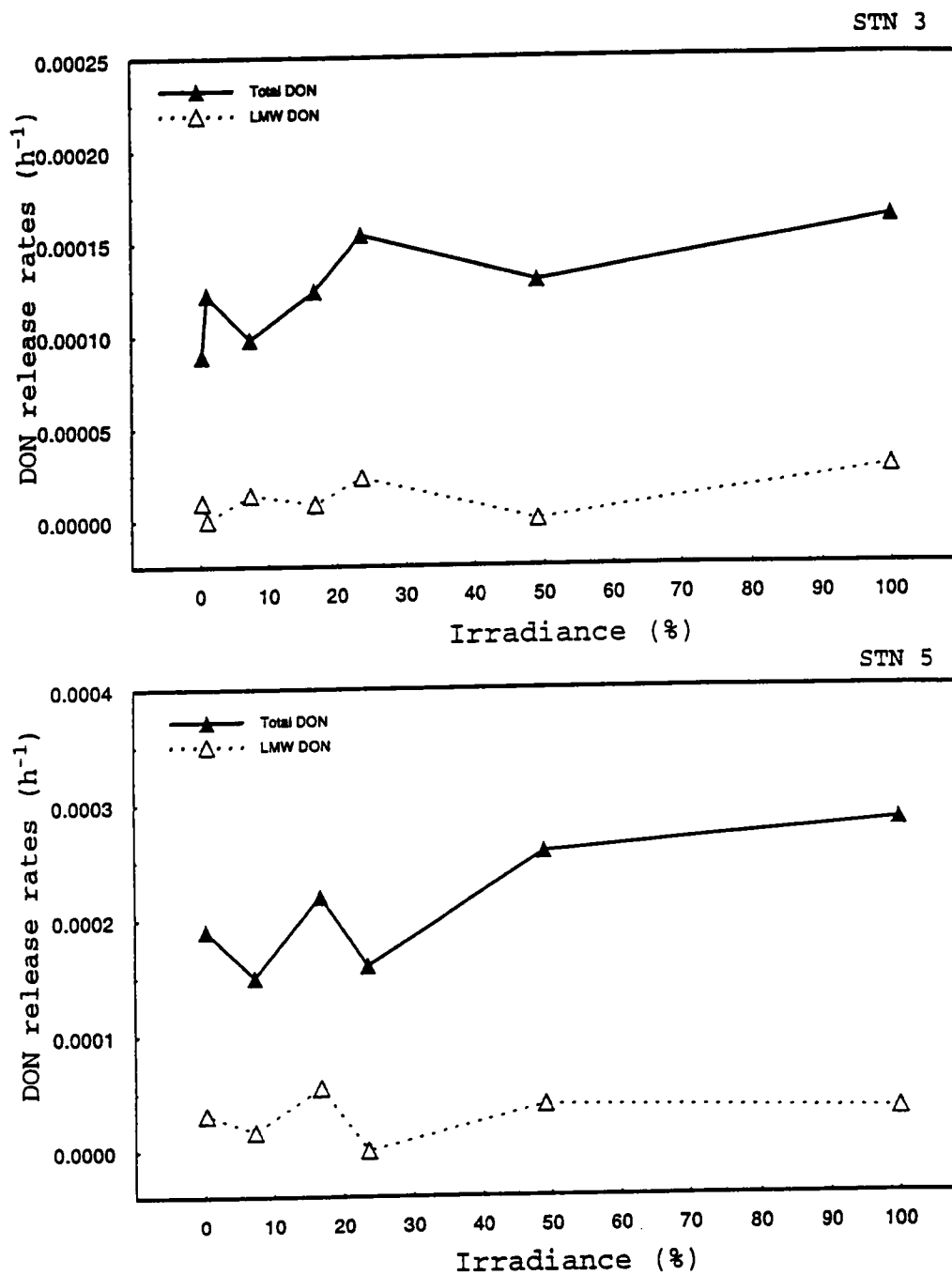


Figure 45. Total and LMW DON release rates vs. per cent surface irradiance at stations 3 and 5 of RSP²-95.

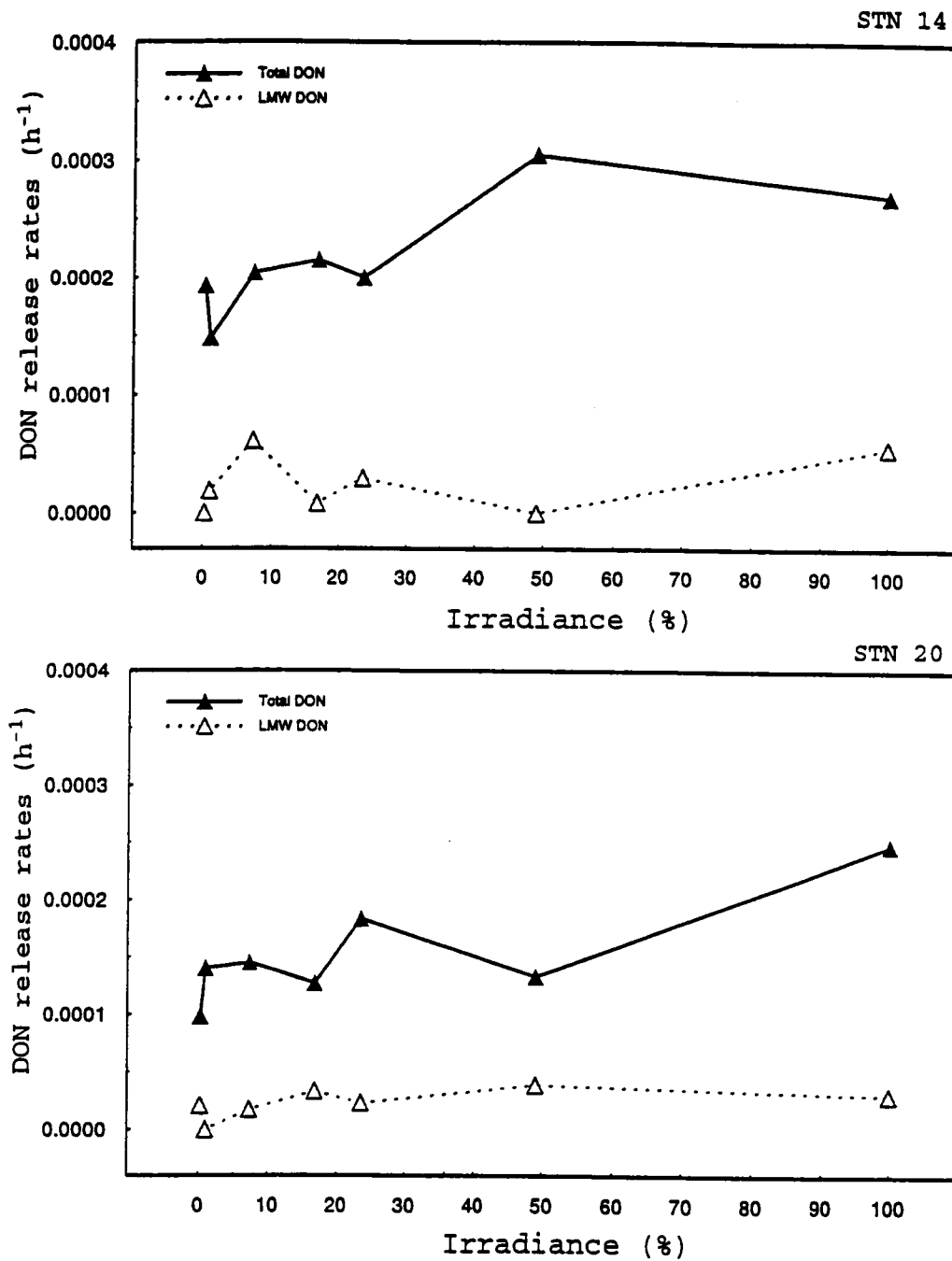


Figure 46. Total and LMW DON release rates vs. per cent surface irradiance at stations 14 and 20 of RSP²-95.

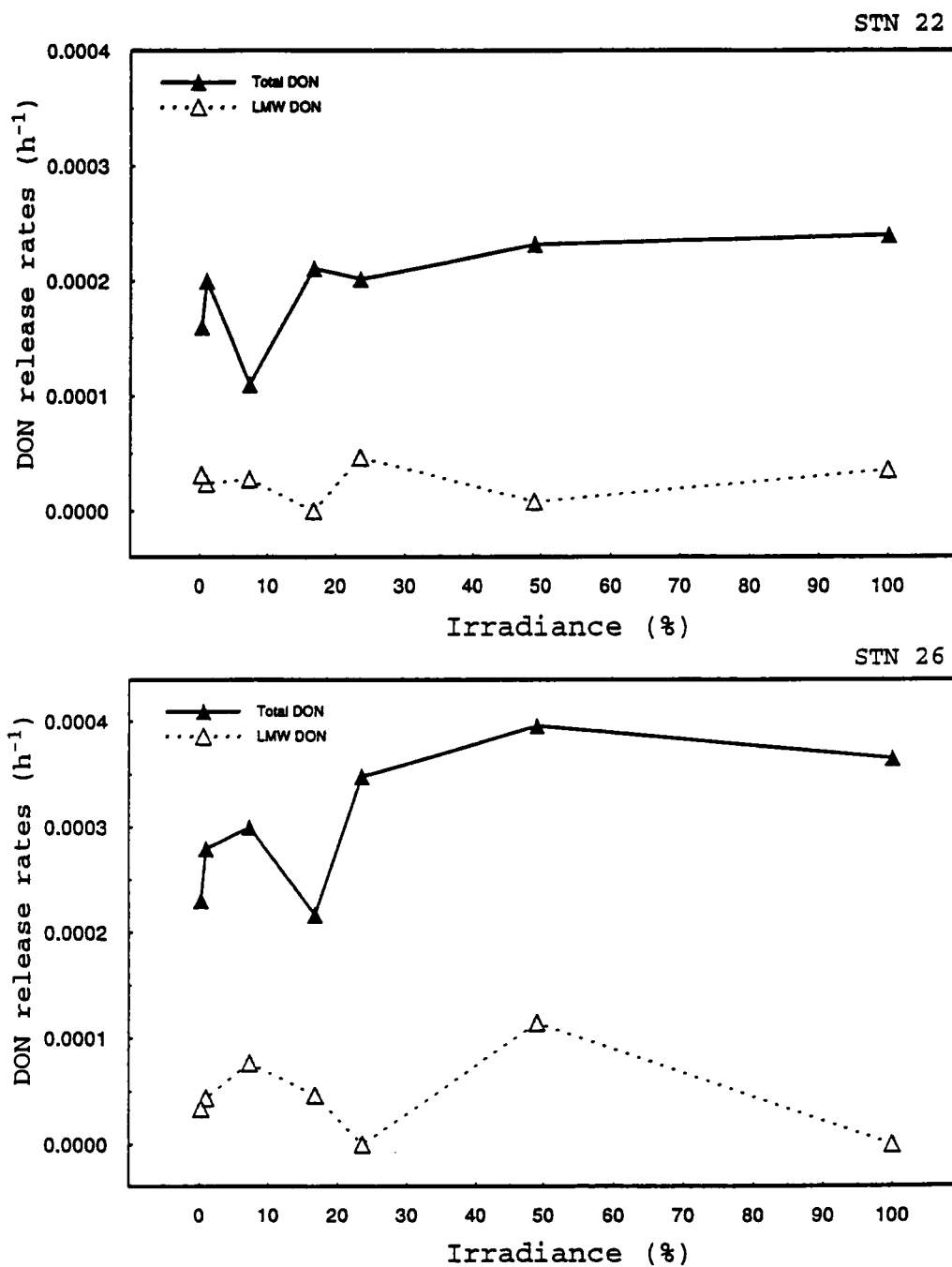


Figure 47. Total and LMW DON release rates vs. per cent surface irradiance at stations 22 and 26 of RSP²-95.

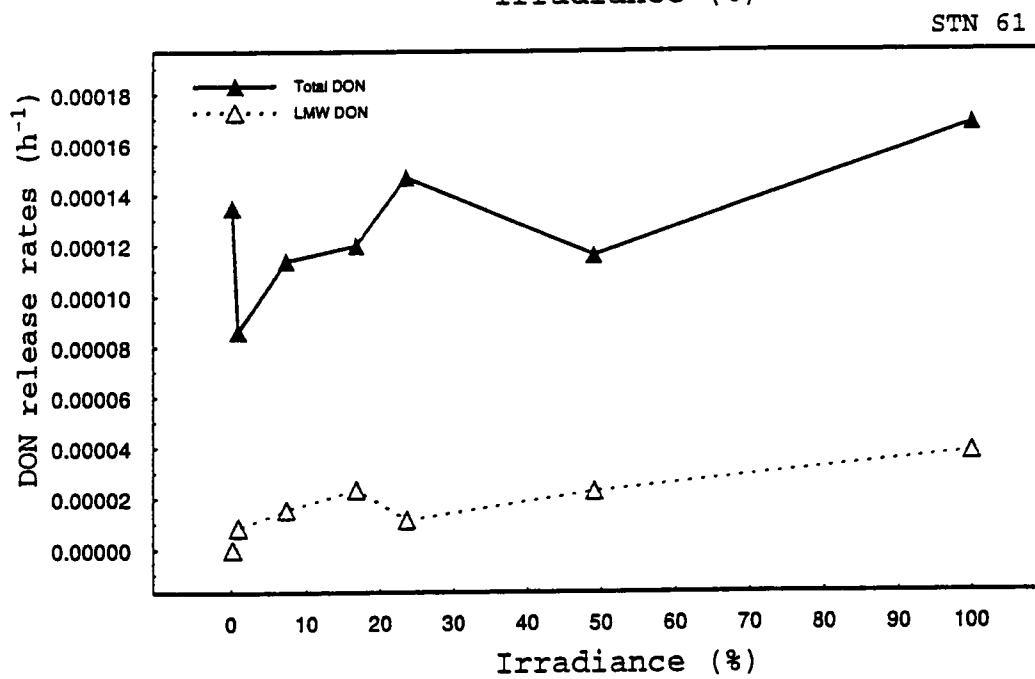
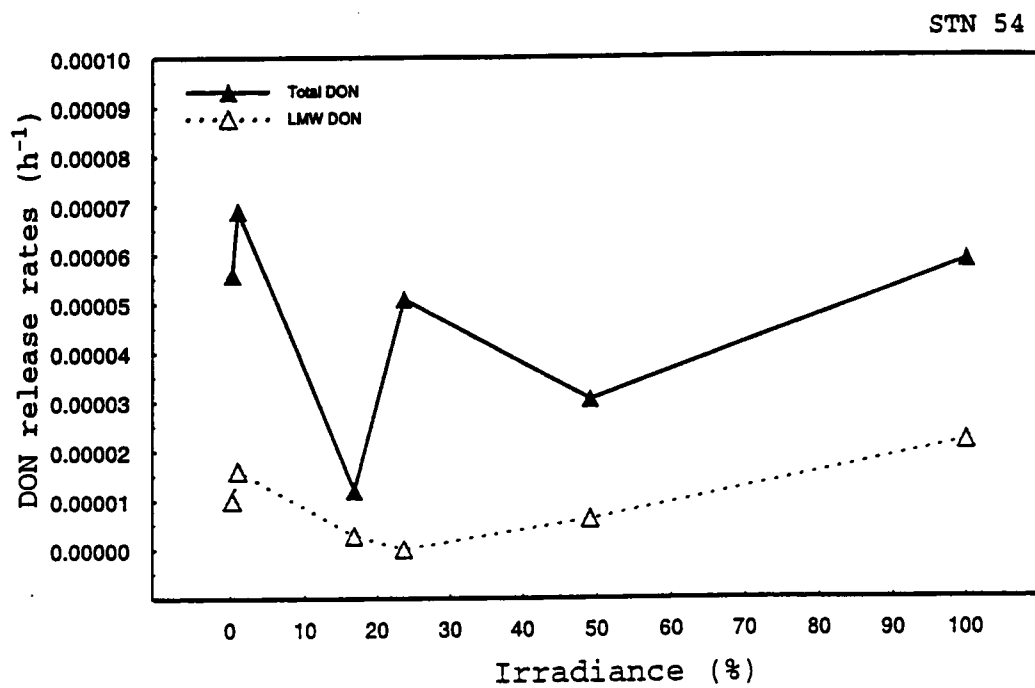
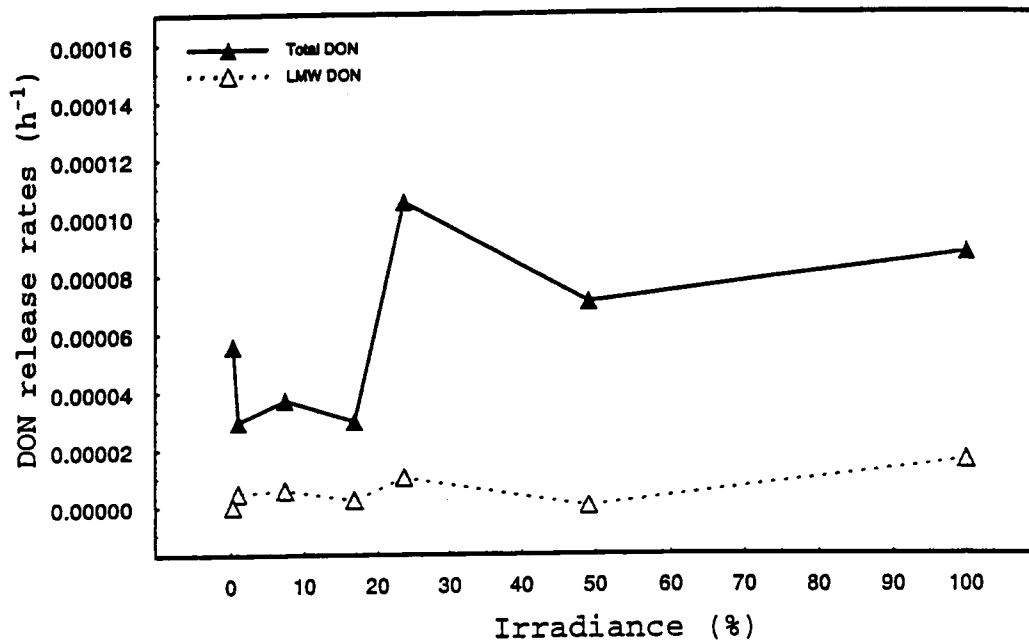


Figure 48. Total and LMW DON release rates vs. per cent surface irradiance at stations 54 and 61 of RSP²-95.

STN 75



STN 79

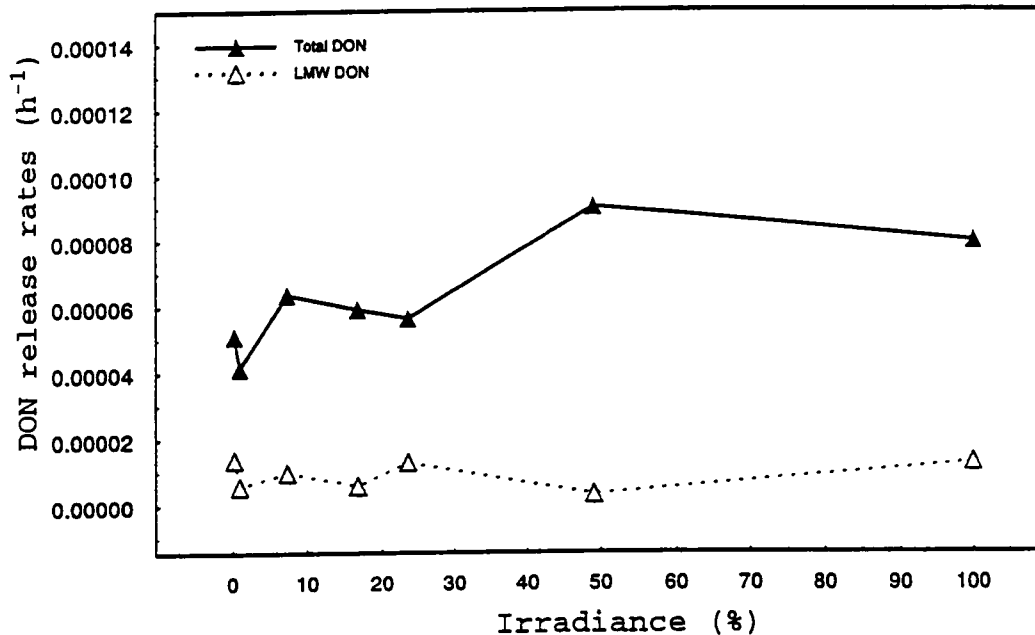


Figure 49. Total and LMW DON release rates vs. per cent surface irradiance at stations 75 and 79 of RSP²-95.

in some stations (e.g., Stations 54 and 61; Figures 48), the increases of LMW DON release rates with irradiance were not significant in other stations (e.g., Stations 3, 5, 20, 22, and 26; Figures 45-47). Analysis of variance on the effects of irradiance on LMW DON release showed that the relationship was not significant (Table 9).

In contrast, the station effects on both total and LMW DON release were significant (Table 9). This indicated that there were spatial and/or temporal variances in total and LMW DON release rates in RSP²-95.

Table 9. Analysis of variance on the effects of irradiance and station on total and LMW DON release rates of RSP²-95.

Source	df	Sum of Squares	Mean Squares	F	p
Total DON					
Station	9	4.13×10^{-7}	4.59×10^{-8}	40.46	0.0001
Irradiance	6	4.55×10^{-8}	7.59×10^{-9}	6.69	0.0001
Error	52	5.90×10^{-8}	1.14×10^{-9}		
LMW DON					
Station	9	8.54×10^{-9}	9.49×10^{-10}	2.65	0.0132
Irradiance	6	1.68×10^{-9}	2.80×10^{-10}	0.78	0.5896
Error	52	1.86×10^{-8}	3.59×10^{-10}		

CHAPTER IV

DISCUSSION

Both laboratory and field experiments in this study suggested that nitrate uptake by Antarctic phytoplankton was strongly dependent on available irradiance. The relationship between nitrate uptake and irradiance can be best described as a strong saturation response (MacIsaac and Dugdale 1972) with photoinhibition occurring at high irradiance levels (Priscu 1989). In RSP²-95, for example, the average nitrate uptake rate at 0.1% irradiance was 0.00038 h^{-1} , representing 12% of the average maximum uptake rate (0.0033 h^{-1}) which was observed at ca. 30% irradiance. In contrast, the average nitrate uptake rate at 100% irradiance was 0.0024 h^{-1} , as 27% lower than the maximum uptake rate.

In earlier studies of nitrate and ammonium in the Ross Sea by Nelson and Smith (1986), nitrate uptake exhibited only a weak dependence on irradiance. They found that nitrate uptake decreased very slowly with depth, and the uptake rate at 0.1% isolume remained ca. 40% of uptake rate in the surface (Nelson and Smith 1986). However, those studies were conducted later in the season (between January 26 and February 2) and samples were taken from an intense diatom bloom. Differences in the response of nitrate uptake to irradiance may occur at different stages of phytoplankton blooms (Olson 1980, Glibert et al. 1982a, Smith and Kattner 1989, Muggli and Smith 1993). Olson (1980) observed that nitrate uptake during early spring in the Scotia Sea was strongly light dependent and apparently

ceased in the dark. Glibert et al. (1982a), however, found that in late summer in the Scotia Sea nitrate uptake was virtually the same at depth as at the surface. In the Fram Strait of the Greenland Sea, Smith and Kattner (1989) observed that nitrate uptake in the summer exhibited a very weak dependence on irradiance (uptake rates at 0.1% isolume remained ca. 50% of the surface rates). Muggli and Smith (1993), however, found that nitrate uptake in the Fram Strait was strongly light-dependent in the spring, and the relationship could be well described by the Priscu's model of nitrate uptake, with both saturation response and photoinhibition included (Priscu 1989). In Cruise RSP²-94 (From November 10 to December 8), the average nitrate uptake rate was 0.0089 h⁻¹, and the optimal irradiance level was ca. 37% surface irradiance. In contrast, in Cruise RSP²-95 the average nitrate uptake rate was 0.0033 h⁻¹, and the optimal irradiance was ca. 31% surface irradiance. Therefore, the average nitrate uptake rate in RSP²-94 was more than two times that of RSP²-95. Furthermore, the earlier phytoplankton bloom in RSP²-94 had experienced more limitation of nitrate uptake by irradiance at depth, a pattern which was also reflected in K_t values. The average K_t for nitrate uptake in RSP²-94 was 9.5% of surface irradiance, whereas the average K_t for nitrate uptake in RSP²-95 was 4.9% surface irradiance (Tables 3-4). The average K_t for nitrate uptake in RSP²-94 was almost twice as high as that in RSP²-95, and higher the K_t values resulted in a greater dependence of nitrate uptake on irradiance, given that saturation was achieved at high irradiance levels. This result confirms that greater dependence of nitrate uptake on irradiance occurs in the earlier

stages of the phytoplankton blooms in the polar regions (Muggli and Smith 1993).

In the laboratory experiments the total DON release on average constituted 15% of the total N uptake (nitrate uptake + DON release) (Appendix A-4). In RSP²-94 the total DON release on average constituted 19% of the total N uptake (Appendix B-4). Finally, in RSP²-95 the total DON release on average constituted 8% of the total N uptake (Appendix C-4). Bronk et al. (1994) reported that an average of 25% to 41% of the dissolved inorganic nitrogen (NH_4^+ and NO_3^-) taken up by phytoplankton in tropical waters was released as dissolved organic nitrogen, and the highest DON release subsequent to nitrate uptake was found in the oceanic Southern Caribbean Sea (74% of the total uptake). In comparison, the per cent release of DON observed in this study was substantially lower; however, the average of total DON release still constituted 8% to 19% of the total N uptake. This indicated that new production was underestimated by ca. 8% to 19% in the NO_3^- -¹⁵N experiments in the Ross Sea (Figure 50). Moreover, higher percentage of DON release relative to the total N uptake was observed deeper in the water column, and the underestimate of new production could be as large as 60% at depth (Figure 51).

The total DON release observed in RSP²-94 was much higher than that of RSP²-95. This could have been caused by a number of factors. First, DON release may change with different states of phytoplankton bloom and productivity (Bronk et al. 1994). For example, it has been found that DON release resulting from nitrate uptake in

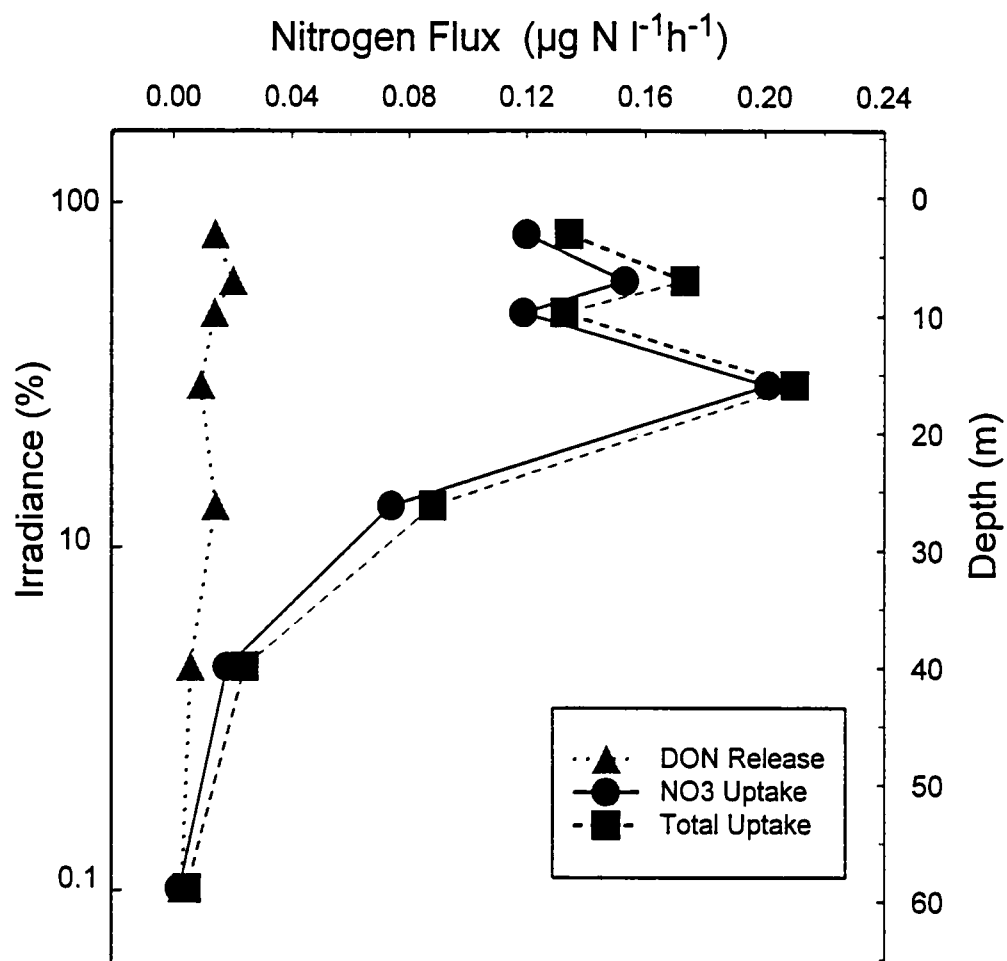


Figure 50. The distribution of DON release, nitrate uptake and total N uptake at Station 9 of RSP²-94.

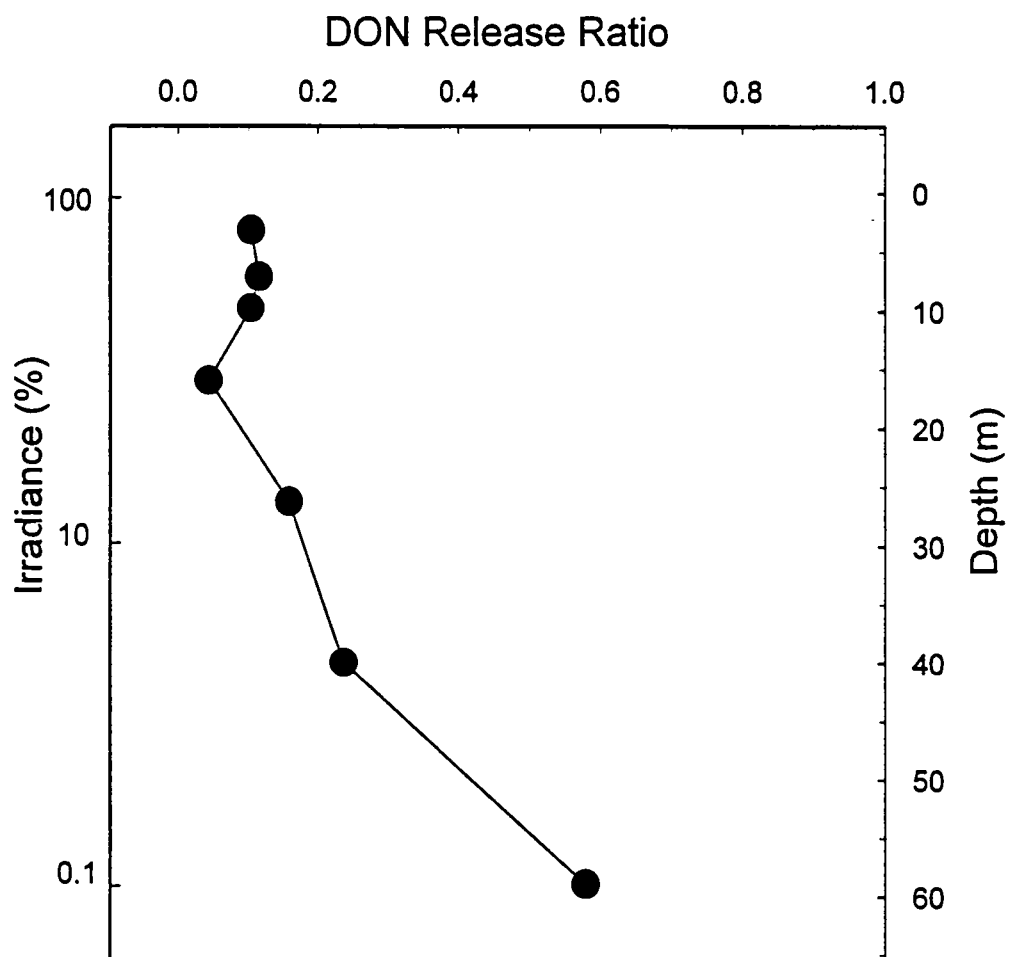


Figure 51. Percentage of the total DON release to total N uptake at Station 9 of RSP²-94.

the Southern California Bight was correlated with primary production (Bronk and Ward 1996). In this study the maximum nitrate uptake rates in RSP²-94 were more than two times of those of RSP²-95 on average, indicating a higher new production during RSP²-94. It was very likely that the higher DON release rate in RSP²-94 was related to higher new production. Secondly, the use of double GF/F filter in RSP²-94 instead of Nuclepore filter might have introduced in a significant percentage of bacterial uptake of nitrate (Bronk and Glibert 1994) because a single GF/F filter can only stop about sixty percent of the bacteria from passing through the filter (Ducklow pers. comm.). Unfortunately, we are lacking adequate bacterial nitrate uptake data to make any comparison. Nevertheless, based on the primary production measured by Smith et al. (1996) and bacterial production measured by Ducklow (unpubl.), bacterial production represents less than two percent of the total primary production in mid-January in the Ross Sea. Therefore, while the bacterial uptake could have inflated the DON release rates by a small amount, they could not account for the major increase of DON release in the field season of RSP²-94.

The LMW DON release relative to total DON release was high in the laboratory experiments, indicating that direct release from the phytoplankton cells might have been the dominant process of DON release, because direct release from the cells is often dominated by LMW components (Mague et al. 1980). Phytoplankton are grown in a more constant environment in the laboratory, with controlled light and temperature and without zooplankton grazing, and thus, the causes of

indirect release of DON had been minimized. In contrast, LMW DON release in RSP²-94 and RSP²-95 were much lower and constituted a smaller fraction of the total DON release (Appendices B-4 and C-4). This suggests that indirect release processes such as the release of DON caused by cell death and lysis, zooplankton grazing, and filtration breakage were the dominant DON release processes.

There were significant effects of irradiance on total DON release in both laboratory and field experiments. However, the effects of irradiance on total DON release were not as strong as those on nitrate uptake. The release rates at 0.1% irradiance remained a significant percentage of those at 100% irradiance (Figure 50). LMW DON release rates were very high in the laboratory experiments and were similar to the total DON release in response to changes of irradiance (Figures 33-37). However, LMW DON release in the field experiments were very low and revealed no dependence on irradiance. Moreover, incubation time and station locations have been shown as the factors that influenced the total and LMW DON release rates significantly (Tables 5-9). This confirms that the release of DON from phytoplankton utilizing inorganic nitrogen is a complex process and no single factor can account for all the variation in DON release rates in the Ross Sea. Irradiance is a factor that influences some of the ecological and physiological processes that result in DON release. However, there might exist many other light-independent processes that influence DON release as well. Further studies both on the rates of DON release and the factors that influence the release rates are needed to understand

the relationship between nitrate uptake and DON release and the new production in the Ross Sea.

CHAPTER V

CONCLUSIONS

1. Nitrate uptake by Phaeocystis sp. in the laboratory was strongly dependent on irradiance, and the relationship can be best described by the Priscu's model of saturation response and photoinhibition (Priscu 1989). Nitrate uptake by phytoplankton (dominated by Phaeocystis or diatoms) in the Ross Sea was also strongly dependent on irradiance, and the relationship can be best described by the Priscu's model of saturation response and photoinhibition.

2. The average maximum nitrate uptake rate achieved by Phaeocystis sp. in the laboratory was 0.0071 h^{-1} , while the optimal irradiance level was ca. 34% irradiance (39.5 to $60.5 \mu\text{E m}^{-2} \text{ S}^{-1}$). Photoinhibition was observed in 4 out of the 5 experiments.

3. The average maximum nitrate uptake rate by phytoplankton (dominated by Phaeocystis) in the Ross Sea during November 10 through December 8, 1994 (RSP²-94) was 0.0089 h^{-1} , while the optimal irradiance level was at ca. 37% of surface irradiance (93 to $179 \mu\text{E m}^{-2} \text{ S}^{-1}$). Photoinhibition was observed in 8 out of 14 stations.

4. The best estimate for the average maximum nitrate uptake rate by phytoplankton (dominated by Phaeocystis or diatoms) in the Ross Sea during December 17, 1995 through January 15, 1996 (RSP²-95) was 0.0033 h^{-1} , while the optimal irradiance level was ca. 31% of surface irradiance (58 to $260 \mu\text{E m}^{-2} \text{ S}^{-1}$). Photoinhibition was observed in 18 out of 23 stations.

5. There were significant effects of irradiance on total DON release both in the laboratory experiments and in the Ross Sea. However, the effects of irradiance on DON release were not as strong as those on nitrate uptake.

6. LMW DON release by Phaeocystis sp. in the laboratory experiments was high and was significantly effected by irradiance, similar to total DON release. However, in the Ross Sea LMW DON release was very low, and the effects of irradiance on LMW DON release were not significant.

7. The release of DON from phytoplankton uptaking nitrate in the Ross Sea resulted in an average of 8% to 19% underestimate of new production during RSP²-94 and RSP²-95.

8. Total DON release in RSP²-94 was much higher than those of RSP²-95. This was probably related to the higher new production of RSP²-94; however, other factors such like light, salinity, zooplankton grazing, and filtration artifacts could also have resulted in the differences in DON release.

9. Higher percentages of LMW DON release were observed in the laboratory experiments, for which direct release could have been one of the dominant DON release processes because direct release from phytoplankton cells is often dominated by LMW component (Mague et al. 1980). LMW DON release was very low in RSP²-94 and RSP²-95, and indirect release such as the release of DON caused by cell death and lysis, as well as by zooplankton grazing were probably the dominant DON release processes.

12. Overall, nitrate uptake by phytoplankton in the Ross Sea in the austral spring and summer of 1994 and 1995 were strongly dependent on irradiance, whereas DON release had a significant but weaker dependence on irradiance during the same time.

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LITERATURE CITED

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APPENDICES

APPENDIX A

Laboratory Experimental Data

A-1. Nitrate, chlorophyll a, and particulate nitrogen concentrations for the laboratory experiments of July 29 and October 14, 1994.

Date of experiment	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
29-Jul-94	65.7	25.03	336.47
17-Oct-94	40.6	20.42	231.24

A-2. Specific and absolute nitrate uptake by *Phaeocystis* sp. in the laboratory experiments of July 29 and October 14, 1994.

Incubation (h)	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
0.5	100	0.0061	2.05
		0.0071	1.64
0.5	50	0.0071	2.38
		0.0066	1.52
0.5	30	0.0066	2.24
		0.0081	1.85
0.5	15	0.0053	1.78
		0.0047	1.09
0.5	5	0.0067	2.25
		0.0043	0.99
0.5	1	0.0044	1.47
		0.0037	0.85
0.5	0.1	0.0030	0.99
		0.0025	0.57
1	100	0.0053	1.78
		0.0057	1.31
1	50	0.0041	1.39
		0.0058	1.35
1	30	0.0044	1.49
		0.0058	1.32
1	15	0.0047	1.57
		0.0046	1.05
1	5	0.0041	1.39
		0.0039	0.90
1	1	0.0025	0.83
		0.0028	0.65
1	0.1	0.0017	0.58
		0.0020	0.47
3	100	0.0034	1.14
		0.0052	1.20
3	50	0.0041	1.37
		0.0057	1.31
3	30	0.0036	1.21
		0.0044	1.02
3	15	0.0037	1.26
		0.0069	1.60
3	5	0.0035	1.17

A-2. cont.

Incubation (h)	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
		0.0049	1.14
3	1	0.0013	0.43
		0.0035	0.80
3	0.1	0.0008	0.28
		0.0009	0.20
5	100	0.0087	2.92
		0.0079	1.82
5	50	0.0052	1.74
		0.0091	2.10
5	30	0.0051	1.71
		0.0116	2.68
5	15	0.0082	2.77
		0.0105	2.42
5	5	0.0048	1.63
		0.0068	1.56
5	1	0.0016	0.55
		0.0018	0.41
5	0.1	0.0006	0.19
		0.0006	0.13
8	100	0.0056	1.89
		0.0074	1.71
8	50	0.0053	1.78
		0.0073	1.67
8	30	0.0050	1.70
		0.0071	1.63
8	15	0.0070	2.36
		0.0044	1.02
8	5	0.0046	1.54
		0.0051	1.18
8	1	0.0018	0.62
		0.0028	0.64
8	0.1	0.0005	0.16
		0.0004	0.09

A-3. Total and LMW DON release by Phaeocystis sp. in the laboratory experiments of July 29 and October 14, 1994.

Incubation (h)	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
0.5	100	0.0011	0.38	0.00037	0.13
		0.0009	0.20	0.00034	0.08
0.5	50	0.0008	0.26	0.00020	0.07
		0.0010	0.22	0.00030	0.07
0.5	30	0.0009	0.30	0.00021	0.07
		0.0006	0.15	0.00032	0.07
0.5	15	0.0008	0.26	0.00032	0.11
		0.0007	0.15	0.00025	0.06
0.5	5	0.0009	0.32	0.00028	0.09
		0.0007	0.16	0.00013	0.03
0.5	1	0.0007	0.23	0.00022	0.07
		0.0004	0.09	0.00012	0.03
0.5	0.1	0.0006	0.21	0.00029	0.10
		0.0004	0.10	0.00023	0.05
1	100	0.0009	0.29	0.00039	0.13
		0.0011	0.25	0.00035	0.08
1	50	0.0007	0.24	0.00016	0.05
		0.0010	0.22	0.00022	0.05
1	30	0.0007	0.23	0.00034	0.11
		0.0005	0.11	0.00017	0.04
1	15	0.0010	0.32	0.00019	0.06
		0.0007	0.16	0.00029	0.07
1	5	0.0007	0.23	0.00031	0.10
		0.0005	0.11	0.00018	0.04
1	1	0.0006	0.20	0.00026	0.09
		0.0004	0.09	0.00017	0.04
1	0.1	0.0006	0.19	0.00013	0.04
		0.0004	0.08	0.00013	0.03
3	100	0.0009	0.30	0.00033	0.11
		0.0008	0.18	0.00040	0.09
3	50	0.0007	0.23	0.00044	0.15
		0.0008	0.19	0.00033	0.08
3	30	0.0007	0.24	0.00030	0.10
		0.0005	0.12	0.00021	0.05
3	15	0.0004	0.13	0.00029	0.10
		0.0006	0.14	0.00024	0.06
3	5	0.0008	0.26	0.00020	0.07

A-3. cont.

Incubation (h)	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
		0.0005	0.11	0.00028	0.07
3	1	0.0006	0.20	0.00016	0.05
		0.0003	0.08	0.00021	0.05
3	0.1	0.0005	0.17	0.00019	0.06
		0.0003	0.06	0.00025	0.06
5	100	0.0010	0.32	0.00047	0.16
		0.0008	0.17	0.00032	0.07
5	50	0.0007	0.23	0.00043	0.14
		0.0009	0.21	0.00030	0.07
5	30	0.0008	0.27	0.00016	0.05
		0.0005	0.12	0.00025	0.06
5	15	0.0007	0.25	0.00019	0.07
		0.0003	0.07	0.00018	0.04
5	5	0.0007	0.22	0.00017	0.06
		0.0006	0.14	0.00007	0.02
5	1	0.0005	0.17	0.00021	0.07
		0.0003	0.07	0.00014	0.03
5	0.1	0.0005	0.17	0.00017	0.06
		0.0004	0.09	0.00005	0.01
8	100	0.0006	0.19	0.00045	0.15
		0.0007	0.17	0.00037	0.09
8	50	0.0009	0.30	0.00029	0.10
		0.0007	0.15	0.00032	0.07
8	30	0.0007	0.22	0.00038	0.13
		0.0003	0.08	0.00024	0.05
8	15	0.0005	0.18	0.00040	0.13
		0.0006	0.14	0.00033	0.08
8	5	0.0003	0.12	0.00026	0.09
		0.0005	0.12	0.00018	0.04
8	1	0.0006	0.21	0.00026	0.09
		0.0003	0.08	0.00015	0.04
8	0.1	0.0006	0.21	0.00022	0.08
		0.0004	0.09	0.00015	0.03

A-4. Total nitrate uptake and per cent release of total and LMW DON by *Phaeocystis* sp. in the laboratory experiments of July 29 and October 14, 1994.

Incubation (h)	Irradiance (%)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
0.5	100	2.43	15.5	5.2	33.5
		1.84	10.9	4.3	39.7
0.5	50	2.64	9.7	2.6	26.7
		1.74	12.7	4.0	31.1
0.5	30	2.53	11.7	2.8	23.8
		2.00	7.4	3.7	50.5
0.5	15	2.04	12.7	5.3	41.9
		1.24	12.3	4.7	38.2
0.5	5	2.57	12.3	3.6	29.3
		1.16	14.2	2.6	18.6
0.5	1	1.70	13.3	4.3	32.8
		0.94	9.7	2.9	30.4
0.5	0.1	1.21	17.7	8.0	45.2
		0.67	15.0	7.9	52.4
1	100	2.07	13.8	6.3	45.9
		1.56	15.9	5.1	32.2
1	50	1.63	14.6	3.2	22.1
		1.57	14.1	3.3	23.2
1	30	1.72	13.2	6.6	49.6
		1.43	7.7	2.8	36.0
1	15	1.89	17.0	3.4	20.1
		1.22	13.5	5.5	40.8
1	5	1.62	14.3	6.4	44.7

A-4. cont.

Incubation (h)	Irradiance (%)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
1	1	1.01	11.2	4.1	36.8
		1.03	19.0	8.4	43.9
		0.75	12.2	5.2	42.8
1	0.1	0.76	24.8	5.5	22.2
		0.55	14.9	5.3	35.6
3	100	1.44	20.9	7.7	36.9
		1.39	13.3	6.7	50.1
3	50	1.61	14.4	9.1	63.5
		1.50	12.7	5.1	40.4
3	30	1.45	16.5	7.0	42.2
		1.14	10.8	4.3	39.6
3	15	1.39	9.5	6.9	72.7
		1.74	8.2	3.2	39.2
3	5	1.43	18.3	4.6	25.1
		1.24	8.6	5.3	61.3
3	1	0.64	31.9	8.5	26.5
		0.88	9.2	5.5	60.1
3	0.1	0.44	37.5	14.5	38.6
		0.26	24.2	22.4	92.7
5	100	3.24	10.0	4.9	48.6
		1.99	8.8	3.7	42.4
5	50	1.97	11.7	7.3	62.8
		2.31	9.2	3.0	32.5
5	30	1.98	13.9	2.6	19.0

A-4. cont.

Incubation (h)	Irradiance (%)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LMW DON in Total DON Release
5	15	2.80	4.4	2.0	46.4
		3.02	8.3	2.2	26.0
		2.50	2.9	1.7	58.3
5	5	1.85	11.9	3.2	26.6
		1.70	8.3	1.0	11.4
5	1	0.72	24.0	9.5	39.7
		0.48	15.4	6.9	44.6
5	0.1	0.36	47.4	15.4	32.5
		0.22	41.2	5.3	13.0
8	100	2.08	9.0	7.3	80.9
		1.89	9.2	4.5	49.5
8	50	2.08	14.5	4.7	32.3
		1.82	8.3	4.1	49.1
8	30	1.92	11.6	6.6	57.0
		1.70	4.6	3.2	69.4
8	15	2.54	7.1	5.3	74.3
		1.16	12.2	6.6	53.7
8	5	1.66	7.1	5.2	73.3
		1.30	9.1	3.1	34.4
8	1	0.83	25.5	10.5	41.0
		0.71	10.6	4.9	46.3
8	0.1	0.37	57.2	20.2	35.3
		0.19	50.6	17.9	35.4

APPENDIX B

RSP²-94 Experimental Data

B-1. Nitrate, chlorophyll a, and particulate nitrogen data
from RSP²-94. nd = no data.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
9	3	30.2	1.14	13.9
9	7	29.9	1.41	20.4
9	10	29.7	1.44	23.4
9	16	30.5	1.25	23.0
9	26	30.0	1.11	21.3
9	40	30.3	0.64	19.4
9	59	31.3	0.09	9.4
9	71	31.5	0.07	7.6
9	91	32.0	0.11	7.6
9	111	32.0	0.13	8.2
9	130	31.0	0.18	0.8
9	151	31.4	0.10	4.0
19	3	24.3	5.02	29.4
19	6	24.2	5.00	38.8
19	10	24.2	4.98	34.8
19	15	25.2	4.11	35.8
19	23	27.6	4.42	32.6
19	35	29.6	2.38	21.9
19	53	30.4	1.52	16.3
19	65	31.1	0.26	5.1
19	80	31.0	0.22	10.2
19	101	31.2	0.22	6.3
19	127	31.2	0.14	3.6
19	150	31.2	0.12	6.3
25	3	29.5	1.27	15.6
25	8	30.2	1.42	21.7
25	14	29.5	1.28	23.5
25	21	29.5	1.29	22.6
25	34	30.8	0.33	6.2
25	51	31.2	0.10	4.7
25	77	31.2	0.07	2.0
25	96	31.4	0.06	2.3
25	102	31.5	0.04	2.2
25	117	31.5	0.07	4.1
25	136	30.7	0.28	7.4
25	152	30.8	0.28	4.5
36	3	28.1	2.79	22.7

B-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
36	5	28.1	2.86	38.3
36	6	28.1	2.68	29.9
36	10	28.2	2.47	30.0
36	15	28.1	2.77	30.2
36	24	28.3	2.94	29.2
36	34	28.4	2.79	28.1
36	51	28.6	2.92	54.3
36	76	29.5	2.17	19.7
36	101	29.8	1.54	15.6
36	126	30.0	1.48	14.0
36	153	30.0	1.42	13.1
37	3	24.7	6.45	49.1
37	4	24.7	6.34	67.7
37	6	24.7	nd	58.2
37	9	24.8	6.54	56.0
37	13	24.7	6.62	56.4
37	21	26.9	4.59	49.0
37	30	29.8	2.02	17.8
37	51	30.4	0.85	23.3
37	76	30.2	1.21	21.2
37	102	30.4	1.01	23.7
37	125	30.5	0.60	13.0
37	152	30.9	0.07	4.0
38	3	25.0	6.41	26.5
38	4	25.0	5.69	45.4
38	5	25.1	5.58	42.2
38	8	25.1	5.47	41.9
38	12	25.1	5.54	35.0
38	15	25.1	5.80	33.9
38	23	28.3	3.16	23.8
38	51	31.3	0.18	5.7
38	76	30.9	0.52	8.1
38	102	31.0	0.33	5.4
38	126	31.4	0.19	3.4
38	153	31.3	0.11	18.9
39	3	29.9	0.29	7.2
39	13	29.9	0.24	10.3

B-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
39	24	29.8	0.33	9.4
39	38	30.1	0.34	11.9
39	48	30.5	0.25	5.9
39	60	30.9	0.15	9.9
39	71	31.4	0.19	3.7
39	92	31.8	0.04	3.7
39	110	31.9	0.05	4.5
39	120	31.9	0.05	2.9
39	136	31.9	0.08	2.4
39	154	31.8	0.05	2.2
47	3	26.8	2.12	47.9
47	5	26.8	2.07	66.8
47	7	26.7	2.03	68.2
47	10	26.8	2.08	46.9
47	16	26.9	2.17	41.5
47	26	28.7	1.69	27.0
47	38	30.2	0.70	32.2
47	51	30.9	0.25	8.2
47	75	31.5	0.15	2.4
47	111	31.7	0.09	0.6
47	125	31.7	0.09	1.1
47	152	31.5	0.09	1.6
53	3	23.6	5.65	38.6
53	5	23.6	5.82	51.9
53	8	23.8	5.45	51.9
53	12	23.7	5.65	49.7
53	18	24.4	5.50	51.7
53	28	26.9	4.18	35.7
53	41	28.1	2.73	22.5
53	60	29.1	1.38	33.0
53	80	31.1	0.19	10.4
53	100	31.5	0.12	7.4
53	125	31.2	0.14	8.7
53	153	31.0	0.14	6.0
56	3	24.3	3.33	42.2
56	4	24.3	4.18	92.6
56	6	24.4	4.28	69.6

B-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
56	10	24.3	4.28	68.8
56	15	24.5	4.22	134.6
56	23	24.7	4.11	47.1
56	35	28.5	1.95	33.7
56	51	31.0	0.21	16.7
56	76	31.1	0.35	14.9
56	101	31.9	0.03	7.2
56	126	31.7	0.04	7.0
56	153	31.5	0.03	8.2
60	3	27.7	2.73	17.7
60	5	27.8	2.75	27.9
60	9	27.7	2.70	33.0
60	14	27.7	2.84	29.0
60	21	27.7	2.94	31.0
60	33	27.7	2.88	31.8
60	50	27.9	2.53	26.7
60	60	26.9	3.74	30.6
60	81	28.9	2.08	23.6
60	101	29.9	0.56	11.3
60	125	30.3	0.73	8.8
60	155	31.0	0.06	1.8
64	3	19.7	8.81	28.7
64	4	19.7	8.62	37.9
64	7	19.8	8.37	31.3
64	10	19.7	8.34	31.3
64	16	19.9	8.59	28.6
64	25	20.5	8.67	27.4
64	38	23.7	6.13	29.7
64	50	25.5	5.00	25.7
64	76	28.5	2.42	27.0
64	100	30.0	0.95	11.6
64	125	31.0	0.19	4.5
64	151	31.1	0.10	3.3
70	0	18.8	7.77	78.4
70	3	19.6	6.16	86.5
70	7	19.1	7.53	80.9
70	9	19.7	6.66	78.5

B-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
70	11	20.9	6.38	76.4
70	15	26.0	3.93	49.7
70	25	26.7	3.35	51.0
70	44	27.7	2.45	17.1
70	77	29.7	1.29	13.3
70	102	31.1	0.11	2.6
70	127	31.2	0.09	4.0
70	152	31.3	0.12	1.5
72	7	22.1	6.53	14.1
72	10	22.2	5.09	76.1
72	13	22.2	6.40	78.5
72	18	22.2	6.35	75.4
72	27	22.2	6.25	40.3
72	40	22.5	7.75	77.5
72	60	26.4	4.48	61.3
72	80	30.4	0.93	20.5
72	100	29.7	0.78	20.6
72	125	30.9	0.51	16.2
72	153	31.4	0.12	39.2

B-2. Specific and absolute nitrate uptake from RSP²-94.

Station No.	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
9	100	0.009	0.12
9	50	0.008	0.15
9	30	0.005	0.12
9	15	0.009	0.20
9	5	0.003	0.07
9	1	0.001	0.02
9	0.1	0.000	0.00
19	100	0.012	0.36
19	50	0.011	0.42
19	30	0.010	0.36
19	15	0.006	0.23
19	5	0.006	0.18
19	1	0.002	0.04
19	0.1	0.001	0.01
25	100	0.002	0.03
25	50	0.002	0.05
25	30	0.002	0.06
25	15	0.002	0.05
25	5	0.002	0.01
25	1	nd	nd
25	0.1	0.000	0.00
36	100	0.008	0.19
36	50	0.009	0.33
36	30	0.010	0.30
36	15	0.008	0.23
36	5	0.006	0.18
36	1	0.001	0.04
36	0.1	0.001	0.03
37	100	0.010	0.50
37	50	0.009	0.58
37	30	0.009	0.53
37	15	0.014	0.79
37	5	0.011	0.63
37	1	0.008	0.41
37	0.1	0.001	0.02
38	100	0.010	0.27
38	50	0.007	0.32
38	30	0.003	0.11

B-2. cont.

Station No.	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
38	15	0.003	0.12
38	5	0.004	0.13
38	1	0.002	0.06
38	0.1	0.001	0.02
39	100	0.002	0.02
39	50	0.002	0.02
39	30	nd	nd
39	15	0.003	0.03
39	5	0.004	0.02
39	1	0.001	0.01
39	0.1	nd	nd
47	100	0.007	0.31
47	50	0.006	0.37
47	30	0.006	0.40
47	15	0.005	0.25
47	5	0.004	0.18
47	1	0.001	0.03
47	0.1	nd	nd
53	100	0.010	0.39
53	50	0.013	0.67
53	30	0.011	0.58
53	15	0.009	0.46
53	5	0.012	0.60
53	1	0.003	0.11
53	0.1	0.001	0.01
56	100	0.008	0.34
56	50	0.010	0.89
56	30	0.009	0.60
56	15	0.009	0.64
56	5	0.008	1.06
56	1	0.001	0.05
56	0.1	0.003	0.10
60	100	0.005	0.09
60	50	0.007	0.19
60	30	0.005	0.17
60	15	0.007	0.20
60	5	nd	nd
60	1	0.002	0.05
60	0.1	0.000	0.01

B-2. cont.

Station No.	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
64	100	0.010	0.29
64	50	0.006	0.23
64	30	0.007	0.22
64	15	0.001	0.04
64	5	0.004	0.11
64	1	0.001	0.03
64	0.1	0.000	0.01
70	100	0.008	0.62
70	50	0.008	0.66
70	30	0.011	0.88
70	15	0.007	0.58
70	5	0.006	0.47
70	1	0.004	0.20
70	0.1	0.001	0.05
72	100	0.007	0.10
72	50	0.008	0.58
72	30	0.008	0.63
72	15	0.011	0.79
72	5	0.010	0.39
72	1	0.005	0.42
72	0.1	0.001	0.04

B-3. Total and LMW DON release from RSP²-94. nd = no data.

Station No.	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
9	100	0.0010	0.014	0.00004	0.0006
9	50	0.0010	0.020	0.00001	0.0001
9	30	0.0006	0.014	0.00004	0.0009
9	15	0.0004	0.009	0.00001	0.0001
9	5	0.0007	0.014	0.00004	0.0008
9	1	0.0003	0.006	0.00000	0.0000
9	0.1	0.0003	0.003	0.00001	0.0001
19	100	0.0014	0.040	0.00003	0.0010
19	50	0.0011	0.041	0.00007	0.0028
19	30	0.0006	0.021	0.00004	0.0013
19	15	0.0008	0.028	0.00005	0.0019
19	5	0.0009	0.029	0.00003	0.0010
19	1	0.0005	0.011	0.00003	0.0007
19	0.1	0.0004	0.007	0.00007	0.0011
25	100	0.0008	0.012	0.00006	0.0009
25	50	0.0005	0.011	0.00000	0.0000
25	30	0.0007	0.016	0.00003	0.0007
25	15	0.0004	0.009	0.00001	0.0002
25	5	0.0007	0.004	0.00006	0.0004
25	1	nd	nd	nd	nd
25	0.1	0.0003	0.001	0.00000	0.0000
36	100	0.0018	0.040	0.00003	0.0007
36	50	0.0013	0.051	0.00009	0.0034
36	30	0.0010	0.029	0.00002	0.0007
36	15	0.0013	0.040	0.00009	0.0027
36	5	0.0005	0.014	0.00005	0.0015
36	1	0.0003	0.010	0.00000	0.0000
36	0.1	0.0002	0.005	0.00002	0.0006
37	100	0.0012	0.061	0.00004	0.0018
37	50	0.0007	0.046	0.00001	0.0005
37	30	0.0011	0.062	0.00005	0.0031
37	15	0.0011	0.061	0.00000	0.0000
37	5	0.0005	0.029	0.00005	0.0028
37	1	0.0005	0.023	0.00002	0.0012
37	0.1	0.0003	0.005	0.00003	0.0006
38	100	0.0014	0.037	0.00000	0.0000
38	50	0.0014	0.064	0.00011	0.0052
38	30	0.0010	0.041	0.00000	0.0000

B-3. cont.

Station No.	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
38	15	0.0005	0.022	0.00005	0.0019
38	5	0.0012	0.041	0.00008	0.0027
38	1	0.0008	0.029	0.00004	0.0015
38	0.1	0.0006	0.014	0.00008	0.0018
39	100	0.0012	0.008	0.00007	0.0005
39	50	0.0006	0.006	0.00007	0.0007
39	30	nd	nd	nd	nd
39	15	0.0013	0.015	0.00013	0.0016
39	5	0.0046	0.027	0.00001	0.0001
39	1	0.0013	0.012	0.00002	0.0002
39	0.1	nd	nd	nd	nd
47	100	0.0011	0.051	0.00007	0.0034
47	50	0.0006	0.041	0.00008	0.0053
47	30	0.0007	0.051	0.00005	0.0031
47	15	0.0004	0.017	0.00000	0.0000
47	5	0.0008	0.035	0.00006	0.0023
47	1	0.0008	0.021	0.00006	0.0017
47	0.1	nd	nd	nd	nd
53	100	0.0015	0.056	0.00011	0.0043
53	50	0.0009	0.045	0.00004	0.0021
53	30	0.0014	0.072	0.00012	0.0061
53	15	0.0013	0.064	0.00012	0.0059
53	5	0.0012	0.062	0.00000	0.0000
53	1	0.0009	0.034	0.00010	0.0034
53	0.1	0.0010	0.023	0.00007	0.0016
56	100	0.0016	0.067	0.00005	0.0023
56	50	0.0011	0.100	0.00007	0.0068
56	30	0.0014	0.095	0.00000	0.0000
56	15	0.0011	0.076	0.00008	0.0056
56	5	0.0005	0.067	0.00005	0.0062
56	1	0.0010	0.045	0.00006	0.0030
56	0.1	0.0009	0.031	0.00009	0.0031
60	100	0.0022	0.039	0.00013	0.0023
60	50	0.0010	0.028	0.00013	0.0036
60	30	0.0007	0.023	0.00000	0.0000
60	15	0.0012	0.035	0.00010	0.0028
60	5	nd	nd	nd	nd
60	1	0.0006	0.021	0.00009	0.0030
60	0.1	0.0008	0.022	0.00009	0.0024

B-3. cont.

Station No.	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
64	100	0.0006	0.017	0.00001	0.0003
64	50	0.0008	0.030	0.00000	0.0000
64	30	0.0004	0.011	0.00001	0.0004
64	15	0.0007	0.022	0.00000	0.0001
64	5	0.0005	0.013	0.00001	0.0004
64	1	0.0004	0.011	0.00001	0.0004
64	0.1	0.0002	0.005	0.00000	0.0000
70	100	0.0009	0.067	0.00005	0.0036
70	50	0.0007	0.063	0.00010	0.0086
70	30	0.0006	0.051	0.00000	0.0000
70	15	0.0008	0.062	0.00005	0.0039
70	5	0.0007	0.051	0.00004	0.0029
70	1	0.0005	0.025	0.00007	0.0033
70	0.1	0.0003	0.016	0.00005	0.0028
72	100	0.0009	0.013	0.00010	0.0014
72	50	0.0007	0.054	0.00008	0.0061
72	30	0.0008	0.065	0.00002	0.0016
72	15	0.0005	0.039	0.00003	0.0020
72	5	0.0006	0.026	0.00000	0.0000
72	1	0.0004	0.032	0.00006	0.0043
72	0.1	0.0003	0.021	0.00004	0.0022

B-4. Total nitrate uptake and per cent release of total and LMW DON from RSP²-94.

Station No.	Irradiance (%)	Depth (m)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
9	100	3	0.13	10.4	0.4	4.2
9	50	7	0.17	11.5	0.1	0.7
9	30	10	0.13	10.4	0.7	6.7
9	15	16	0.21	4.4	0.1	1.3
9	5	26	0.09	15.9	1.0	6.1
9	1	40	0.02	23.7	0.0	0.0
9	0.1	59	0.00	58.0	2.0	3.4
19	100	3	0.40	10.0	0.2	2.5
19	50	6	0.46	9.0	0.6	6.7
19	30	10	0.38	5.5	0.3	6.1
19	15	15	0.25	10.9	0.8	7.0
19	5	23	0.21	13.7	0.5	3.4
19	1	35	0.05	22.3	1.5	6.6
19	0.1	53	0.02	42.5	6.4	15.1
25	100	3	0.05	25.5	1.9	7.3
25	50	8	0.06	17.5	0.0	0.0
25	30	14	0.07	21.4	0.9	4.3
25	15	21	0.06	16.2	0.3	1.9
25	5	34	0.01	27.8	2.5	9.1
25	1	51	nd	nd	nd	nd
25	0.1	77	0.00	62.3	0.0	0.0
36	100	3	0.23	17.3	0.3	1.7
36	50	5	0.38	13.5	0.9	6.7
36	30	6	0.33	8.9	0.2	2.4
36	15	10	0.27	14.8	1.0	6.7

B-4. cont.

Station No.	Irradiance (%)	Depth (m)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
36	5	15	0.19	7.2	0.8	11.0
36	1	24	0.05	20.7	0.0	0.0
36	0.1	34	0.03	16.2	1.8	11.1
37	100	3	0.56	10.9	0.3	2.9
37	50	4	0.63	7.3	0.1	1.2
37	30	6	0.59	10.5	0.5	4.9
37	15	9	0.85	7.2	0.0	0.0
37	5	13	0.66	4.4	0.4	9.7
37	1	21	0.43	5.3	0.3	5.1
37	0.1	30	0.02	21.1	2.5	11.8
38	100	3	0.31	12.1	0.0	0.0
38	50	4	0.38	16.7	1.4	8.1
38	30	5	0.15	26.9	0.0	0.0
38	15	8	0.14	15.1	1.4	9.1
38	5	12	0.18	23.3	1.5	6.6
38	1	15	0.08	33.9	1.8	5.2
38	0.1	23	0.04	40.3	5.1	12.7
39	100	3	0.02	36.0	2.1	5.9
39	50	13	0.03	21.6	2.7	12.3
39	30	24	nd	nd	nd	nd
39	15	38	0.05	31.2	3.2	10.4
39	5	48	0.05	54.6	0.1	0.2
39	1	60	0.02	60.9	0.8	1.2
39	0.1	71	nd	nd	nd	nd
47	100	3	0.37	13.9	0.9	6.8
47	50	5	0.41	9.9	1.3	12.9

B-4. cont.

Station No.	Irradiance (%)	Depth (m)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
47	30	7	0.45	11.2	0.7	6.2
47	15	10	0.27	6.4	0.0	0.0
47	5	16	0.22	15.9	1.1	6.6
47	1	26	0.05	40.7	3.3	8.1
47	0.1	38	nd	nd	nd	nd
53	100	3	0.44	12.7	1.0	7.7
53	50	5	0.72	6.3	0.3	4.6
53	30	8	0.65	11.1	0.9	8.3
53	15	12	0.53	12.1	1.1	9.3
53	5	18	0.66	9.4	0.0	0.0
53	1	28	0.15	23.3	2.4	10.1
53	0.1	41	0.04	62.0	4.3	6.9
56	100	3	0.40	16.7	0.6	3.4
56	50	4	0.99	10.1	0.7	6.8
56	30	6	0.70	13.6	0.0	0.1
56	15	10	0.71	10.7	0.8	7.4
56	5	15	1.12	6.0	0.6	9.2
56	1	23	0.09	48.2	3.2	6.6
56	0.1	35	0.13	24.2	2.4	10.1
60	100	3	0.13	30.4	1.8	6.0
60	50	5	0.21	13.2	1.7	12.7
60	30	9	0.19	12.1	0.0	0.0
60	15	14	0.23	15.2	1.2	8.0
60	5	21	nd	nd	nd	nd
60	1	33	0.07	29.2	4.2	14.5
60	0.1	50	0.03	80.8	9.0	11.1

B-4. cont.

Station No.	Irradiance (%)	Depth (m)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LMW DON in Total DON Release
64	100	3	0.31	5.6	0.1	1.8
64	50	4	0.26	11.6	0.0	0.0
64	30	7	0.23	4.9	0.2	3.7
64	15	10	0.07	32.7	0.2	0.6
64	5	16	0.12	10.6	0.3	3.2
64	1	25	0.04	27.2	1.0	3.8
64	0.1	38	0.01	40.3	0.0	0.0
70	100	0	0.68	9.8	0.5	5.4
70	50	3	0.72	8.7	1.2	13.6
70	30	7	0.93	5.4	0.0	0.0
70	15	9	0.65	9.6	0.6	6.3
70	5	11	0.52	9.8	0.6	5.8
70	1	15	0.23	11.1	1.4	12.8
70	0.1	25	0.06	26.0	4.4	17.0
72	100	6	0.12	11.0	1.2	11.0
72	50	7	0.63	8.5	1.0	11.3
72	30	10	0.69	9.4	0.2	2.4
72	15	13	0.83	4.7	0.2	5.1
72	5	18	0.41	6.2	0.0	0.0
72	1	27	0.45	7.2	1.0	13.5
72	0.1	40	0.06	37.2	3.8	10.3
Mean				19.4	1.3	6.3

APPENDIX C

RSP²-95 Experimental Data

C-1. Nitrate, chlorophyll a, and particulate nitrogen data
from RSP²-95. nd = no data.

Station No.	Depth (m)	Nitrate (μ M)	Chlorophyll a (μ g l ⁻¹)	PN (μ g N l ⁻¹)
3	0	21.6	5.93	60.7
3	3	21.7	5.93	96.9
3	5	21.7	5.82	86.9
3	8	21.8	5.82	90.8
3	13	22.6	5.71	84.4
3	20	22.8	5.79	79.6
3	30	26.7	5.57	57.9
3	50	25.2	6.18	57.4
3	75	29.7	1.14	10.4
3	100	29.8	1.12	12.4
3	150	30.1	1.11	11.6
4	0	23.7	5.43	62.3
4	4	23.9	5.64	70.2
4	7	23.9	5.79	68.8
4	10	25.9	4.50	51.8
4	16	28.5	2.66	26.9
4	25	29.0	2.04	23.1
4	38	30.3	0.76	7.7
4	50	30.7	0.44	5.5
4	75	30.6	0.33	3.2
4	100	30.7	0.10	4.1
4	125	31.0	0.06	3.1
4	150	30.9	0.04	6.6
5	0	22.5	6.14	61.9
5	3	22.6	6.14	77.6
5	5	22.6	6.11	75.7
5	8	22.7	6.04	78.1
5	13	22.7	5.89	71.7
5	20	23.7	7.46	78.5
5	30	25.8	8.71	59.3
5	50	29.7	1.15	8.2
5	75	30.4	0.68	4.6
5	100	30.5	0.56	4.2
5	150	30.8	0.20	3.0
9	0	22.6	7.14	72.2
9	3	22.6	7.14	80.7
9	5	22.6	6.79	85.1
9	7	22.7	6.86	83.5

C-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
9	11	23.1	6.93	77.3
9	17	23.2	6.86	76.5
9	25	23.1	6.96	76.6
9	50	30.5	0.29	5.2
9	75	30.4	0.45	6.0
9	100	30.2	0.87	6.4
9	150	31.0	0.21	2.7
14	0	22.4	8.21	66.5
14	3	22.2	8.21	68.3
14	5	22.2	8.61	79.0
14	8	22.3	9.04	83.4
14	11	22.3	8.61	77.7
14	23	22.5	8.46	83.4
14	40	22.9	9.36	80.1
14	50	24.1	8.79	68.1
14	75	29.6	6.18	15.3
14	100	27.8	1.51	35.3
14	150	30.7	4.79	7.6
20	0	20.9	3.33	67.8
20	3	20.9	3.33	67.8
20	5	20.8	4.57	76.5
20	7	20.9	3.41	73.7
20	11	21.3	5.29	75.2
20	18	21.9	6.68	87.8
20	26	22.0	6.07	77.9
20	35	22.3	5.04	82.0
20	50	22.4	6.39	77.6
20	75	25.5	3.57	50.5
20	100	27.8	3.45	36.6
20	150	28.6	2.65	39.6
22	0	12.4	3.40	79.4
22	3	12.9	3.40	97.3
22	5	13.0	3.57	98.1
22	8	13.6	4.32	106.7
22	13	15.1	5.82	136.0
22	20	17.0	7.64	139.2
22	30	18.4	7.32	113.4
22	50	20.2	6.46	111.4

C-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
22	75	27.2	4.43	69.1
22	100	29.5	2.02	21.9
22	125	30.0	0.71	10.2
22	150	30.1	0.58	8.4
23	0	16.9	6.29	41.2
23	4	16.8	6.68	62.1
23	6	16.9	5.50	59.7
23	10	22.7	12.08	71.5
23	15	23.8	11.11	74.6
23	23	23.3	8.04	63.0
23	50	29.9	1.76	16.9
23	75	30.6	0.80	7.6
23	92	31.0	0.42	5.0
23	150	31.2	0.26	3.6
25	0	16.6	6.57	72.7
25	3	16.4	6.57	100.3
25	4	16.3	5.21	123.2
25	6	17.1	7.86	96.8
25	10	19.4	7.86	85.3
25	15	20.9	8.86	87.9
25	23	24.8	7.50	59.7
25	50	30.7	0.80	5.0
25	75	31.0	0.21	2.7
25	100	30.8	0.25	2.9
25	125	30.6	0.47	5.2
25	150	30.6	0.39	4.2
26	0	15.7	2.23	48.8
26	4	15.6	2.04	61.0
26	7	16.1	3.04	62.8
26	10	16.2	3.48	57.6
26	16	16.6	3.44	66.0
26	25	23.0	5.11	60.3
26	38	26.6	6.11	59.8
26	50	30.1	4.46	34.6
26	75	30.5	1.57	11.8
26	100	30.6	0.93	7.2
26	150	30.8	0.59	7.6
28	0	13.5	4.63	66.4

C-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
28	3	13.3	4.63	66.4
28	5	14.0	4.52	84.3
28	8	15.0	4.97	87.0
28	13	16.2	5.03	85.4
28	20	18.4	4.07	137.0
28	30	21.6	5.88	62.4
28	50	24.8	7.10	53.2
28	75	29.0	4.73	38.5
28	100	30.0	3.86	22.0
28	150	30.1	0.81	8.7
31	0	16.0	3.39	71.9
31	3	15.8	3.39	78.2
31	6	15.6	3.55	76.7
31	9	15.7	3.86	78.6
31	15	16.5	1.86	86.9
31	23	17.2	4.79	76.1
31	34	20.1	8.04	73.4
31	50	22.0	7.79	77.4
31	75	29.3	4.57	40.2
31	100	31.9	0.85	7.9
31	125	29.9	0.64	6.2
31	150	30.3	0.33	13.4
35	0	18.1	1.68	63.8
35	5	18.0	1.72	58.2
35	8	17.8	1.86	59.7
35	12	17.7	1.94	62.0
35	20	16.9	3.50	70.6
35	3	20.4	1.68	70.0
35	45	22.5	8.04	71.3
35	55	25.2	8.00	81.6
35	75	29.8	2.65	21.9
35	100	30.8	1.72	17.1
35	125	31.7	0.33	4.6
35	150	31.7	0.22	3.4
40	0	14.4	2.33	58.5
40	3	14.3	2.33	58.5
40	5	14.3	2.60	75.5
40	8	14.3	2.07	73.7

C-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
40	13	15.2	3.44	60.2
40	20	16.6	3.86	33.9
40	30	23.2	3.45	28.8
40	50	27.7	3.79	28.8
40	75	30.1	2.93	22.4
40	100	30.5	1.93	14.6
40	150	30.9	0.43	5.7
42	0	9.9	5.00	146.2
42	3	10.9	5.00	129.4
42	5	11.9	5.39	114.3
42	7	15.7	3.82	93.2
42	11	19.0	3.75	74.9
42	18	25.8	4.00	52.3
42	26	29.6	2.14	17.5
42	40	30.3	1.37	12.2
42	60	30.6	0.68	4.7
42	80	30.6	0.41	5.0
42	100	30.6	0.39	3.5
42	150	30.6	0.22	nd
54	0	22.1	1.45	46.9
54	4	22.1	1.29	62.6
54	7	22.1	1.42	57.0
54	11	22.2	1.46	43.6
54	18	21.9	1.31	49.3
54	28	22.1	1.39	55.1
54	42	21.2	1.26	58.0
54	50	21.7	1.83	36.4
54	75	23.5	3.79	55.0
54	100	26.3	7.00	64.0
54	150	30.0	2.24	28.4
58	0	18.4	1.29	36.4
58	6	18.3	0.55	47.7
58	11	18.3	1.02	46.3
58	17	18.4	0.46	47.3
58	26	18.7	1.57	43.3
58	40	21.0	2.13	46.9
58	60	25.9	3.18	35.7
58	75	27.5	2.40	32.0

C-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
58	90	28.3	1.75	28.8
58	105	29.9	1.53	21.5
58	125	30.3	1.53	19.6
58	150	30.0	0.90	11.7
61	0	20.2	3.22	60.7
61	3	28.4	3.22	61.4
61	4	29.6	3.20	64.5
61	7	30.1	3.35	70.8
61	11	30.8	2.79	65.4
61	18	31.1	3.34	62.9
61	26	31.4	4.82	60.6
61	50	31.5	2.94	25.9
61	75	31.5	0.89	9.6
61	100	31.5	0.53	11.9
61	150	31.5	0.39	6.7
65	0	23.8	11.83	41.4
65	4	23.6	1.79	41.1
65	7	23.7	1.46	37.3
65	11	23.2	2.58	53.3
65	18	23.6	2.82	50.2
65	27	25.3	4.32	46.7
65	40	27.0	4.82	43.0
65	60	28.4	3.40	26.0
65	80	29.4	2.09	14.1
65	100	30.6	0.66	3.8
65	125	30.7	0.45	1.6
65	150	31.0	0.29	1.4
75	0	23.7	1.40	82.2
75	5	23.7	1.06	91.6
75	8	23.8	1.29	79.8
75	13	24.1	1.52	82.7
75	20	24.2	1.84	98.7
75	31	24.4	1.90	92.7
75	47	24.7	1.84	79.0
75	60	24.9	1.86	48.9
75	80	26.0	1.78	40.3
75	100	26.3	1.69	24.2
75	150	28.4	1.26	23.3

C-1. cont.

Station No.	Depth (m)	Nitrate (μM)	Chlorophyll a ($\mu\text{g l}^{-1}$)	PN ($\mu\text{g N l}^{-1}$)
79	0	25.2	0.66	9.5
79	8	24.9	0.58	62.4
79	13	24.8	1.22	7.6
79	22	24.9	1.24	7.4
79	34	24.8	1.48	6.2
79	53	25.1	1.09	6.4
79	78	29.2	1.18	nd
79	90	30.8	0.67	4.3
79	100	31.1	0.69	4.0
79	110	31.3	0.59	nd
79	130	31.3	0.29	3.9
79	150	31.3	0.20	3.4
81	0	22.5	0.93	44.3
81	6	22.3	0.89	46.6
81	11	21.8	0.75	39.6
81	17	21.6	0.67	40.1
81	26	21.5	0.79	40.0
81	40	22.1	0.91	33.9
81	60	23.0	1.17	27.2
81	80	25.2	1.23	23.6
81	100	27.3	1.03	19.9
81	115	30.1	0.70	16.2
81	130	28.9	0.79	17.4
86	0	14.8	1.55	46.8
86	3	15.2	1.55	57.4
86	5	15.3	1.97	56.2
86	8	16.5	2.89	71.4
86	13	17.4	3.64	95.2
86	20	20.0	4.61	68.3
86	30	27.1	6.00	57.0
86	50	30.7	1.99	17.6
86	75	31.0	0.84	8.2
86	100	31.1	0.54	5.6
86	125	31.1	0.38	4.5
86	150	31.2	0.30	5.6

C-2. Specific and absolute nitrate uptake from RSP²-95.

Station No.	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
3	100	0.0020	0.12
3	50	0.0030	0.29
3	30	0.0047	0.41
3	15	0.0041	0.38
3	5	0.0023	0.20
3	1	0.0019	0.15
3	0.1	0.0002	0.01
4	100	0.0066	0.41
4	50	0.0064	0.45
4	30	0.0062	0.43
4	15	0.0044	0.23
4	5	0.0017	0.05
4	1	0.0003	0.01
4	0.1	0.0049	0.04
5	100	0.0006	0.03
5	50	0.0056	0.44
5	30	0.0049	0.37
5	15	0.0034	0.27
5	5	0.0048	0.35
5	1	nd	nd
5	0.1	0.0004	0.02
9	100	0.0030	0.21
9	50	0.0045	0.36
9	30	0.0051	0.44
9	15	0.0033	0.28
9	5	0.0039	0.30
9	1	0.0029	0.22
9	0.1	0.0002	0.01
14	100	0.0023	0.15
14	50	0.0055	0.37
14	30	0.0055	0.44
14	15	0.0057	0.47
14	5	0.0054	0.42
14	1	0.0044	0.37

C-2. cont.

Station No.	Irradiance (%)	Specific uptake (h^{-1})	Absolute uptake ($\mu\text{g N l}^{-1} \text{h}^{-1}$)
14	0.1	0.0003	0.03
20	100	0.0044	0.30
20	50	0.0033	0.22
20	30	0.0045	0.34
20	15	0.0037	0.27
20	5	0.0010	0.08
20	1	0.0033	0.29
20	0.1	0.0001	0.01
22	100	0.0025	0.20
22	50	0.0033	0.32
22	30	0.0029	0.29
22	15	0.0032	0.34
22	5	0.0024	0.32
22	1	0.0020	0.28
22	0.1	0.0001	0.02
23	100	0.0046	0.19
23	50	0.0043	0.27
23	30	0.0012	0.07
23	15	0.0032	0.23
23	5	0.0034	0.25
23	1	0.0012	0.07
23	0.1	0.0001	0.00
25	100	0.0042	0.30
25	50	0.0069	0.69
25	30	0.0059	0.73
25	15	0.0051	0.50
25	5	0.0065	0.55
25	1	0.0028	0.24
25	0.1	0.0002	0.01
26	100	0.0047	0.23
26	50	0.0053	0.33
26	30	0.0054	0.34
26	15	0.0051	0.29

C-2. cont.

Station No.	Irradiance (%)	Specific uptake (h^{-1})	Absolute uptake ($\mu\text{g N l}^{-1} \text{h}^{-1}$)
26	5	0.0040	0.26
26	1	0.0019	0.11
26	0.1	0.0002	0.01
28	100	0.0032	0.21
28	50	0.0043	0.28
28	30	0.0047	0.40
28	15	0.0022	0.19
28	5	0.0027	0.23
28	1	0.0015	0.20
28	0.1	0.0002	0.01
31	100	0.0048	0.35
31	50	0.0056	0.44
31	30	0.0053	0.40
31	15	0.0043	0.34
31	5	0.0030	0.26
31	1	0.0019	0.15
31	0.1	0.0001	0.01
35	100	0.0016	0.10
35	50	0.0018	0.12
35	30	0.0017	0.10
35	15	0.0017	0.10
35	5	0.0015	0.09
35	1	0.0006	0.04
35	0.1	0.0001	0.01
40	100	0.0020	0.12
40	50	0.0025	0.15
40	30	0.0031	0.23
40	15	0.0024	0.18
40	5	0.0014	0.08
40	1	0.0005	0.02
40	0.1	0.0002	0.01
42	100	0.0006	0.09
42	50	0.0008	0.10

C-2. cont.

Station No.	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
42	30	0.0008	0.09
42	15	0.0010	0.09
42	5	0.0009	0.07
42	1	0.0004	0.02
42	0.1	0.0002	0.00
54	100	0.0005	0.02
54	50	0.0007	0.04
54	30	0.0006	0.04
54	15	0.0007	0.03
54	5	nd	nd
54	1	0.0002	0.01
54	0.1	0.0001	0.01
58	100	0.0006	0.02
58	50	0.0008	0.04
58	30	0.0008	0.04
58	15	0.0008	0.04
58	5	0.0005	0.02
58	1	0.0003	0.01
58	0.1	0.0001	0.00
61	100	0.0022	0.14
61	50	0.0020	0.12
61	30	0.0026	0.17
61	15	0.0023	0.16
61	5	0.0019	0.12
61	1	0.0003	0.02
61	0.1	0.0002	0.01
65	100	0.0013	0.05
65	50	0.0010	0.04
65	30	0.0010	0.04
65	15	0.0011	0.06
65	5	0.0005	0.03
65	1	0.0004	0.02
65	0.1	0.0002	0.01

C-2. cont.

Station No.	Irradiance (%)	Specific uptake (h ⁻¹)	Absolute uptake (μg N l ⁻¹ h ⁻¹)
75	100	0.0014	0.12
75	50	0.0014	0.13
75	30	0.0015	0.12
75	15	0.0009	0.07
75	5	0.0007	0.07
75	1	0.0003	0.03
75	0.1	0.0002	0.01
79	100	0.0011	0.01
79	50	0.0016	0.10
79	30	0.0011	0.01
79	15	0.0014	0.01
79	5	0.0008	0.00
79	1	0.0003	0.00
79	0.1	0.0002	0.00
81	100	0.0003	0.01
81	50	0.0004	0.02
81	30	0.0003	0.01
81	15	0.0003	0.01
81	5	0.0002	0.01
81	1	0.0001	0.00
81	0.1	0.0001	0.00
86	100	0.0018	0.09
86	50	0.0030	0.17
86	30	0.0022	0.12
86	15	0.0029	0.21
86	5	0.0025	0.23
86	1	0.0012	0.08
86	0.1	0.0002	0.01

C-3. Total and LMW DON release from RSP²-95.

Station No.	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
3	100	0.00016	0.010	0.00003	0.0017
3	50	0.00013	0.013	0.00000	0.0000
3	30	0.00015	0.013	0.00002	0.0020
3	15	0.00012	0.011	0.00001	0.0008
3	5	0.00010	0.008	0.00001	0.0011
3	1	0.00012	0.010	0.00000	0.0000
3	0.1	0.00009	0.005	0.00001	0.0006
5	100	0.00028	0.018	0.00003	0.0021
5	50	0.00026	0.020	0.00004	0.0030
5	30	0.00016	0.012	0.00000	0.0000
5	15	0.00022	0.017	0.00005	0.0042
5	5	0.00015	0.011	0.00002	0.0012
5	1	nd	nd	nd	nd
5	0.1	0.00019	0.011	0.00003	0.0019
14	100	0.00027	0.018	0.00006	0.0037
14	50	0.00031	0.021	0.00000	0.0000
14	30	0.00020	0.016	0.00003	0.0023
14	15	0.00022	0.018	0.00001	0.0007
14	5	0.00020	0.016	0.00006	0.0047
14	1	0.00015	0.012	0.00002	0.0015
14	0.1	0.00019	0.015	0.00000	0.0000
20	100	0.00025	0.017	0.00003	0.0020
20	50	0.00013	0.009	0.00004	0.0026
20	30	0.00018	0.014	0.00002	0.0018
20	15	0.00013	0.009	0.00003	0.0024
20	5	0.00015	0.011	0.00002	0.0013
20	1	0.00014	0.012	0.00000	0.0000
20	0.1	0.00010	0.008	0.00002	0.0016
22	100	0.00024	0.019	0.00004	0.0029
22	50	0.00023	0.023	0.00001	0.0008
22	30	0.00020	0.020	0.00005	0.0046
22	15	0.00021	0.023	0.00000	0.0000
22	5	0.00011	0.015	0.00003	0.0038
22	1	0.00020	0.028	0.00002	0.0033
22	0.1	0.00016	0.018	0.00003	0.0036
26	100	0.00037	0.018	0.00000	0.0000

C-3. cont.

Station No.	Irradiance (%)	Total DON Release		LMW DON Release	
		(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)	(h ⁻¹)	(μg N l ⁻¹ h ⁻¹)
26	50	0.00040	0.024	0.00011	0.0070
26	30	0.00035	0.022	0.00000	0.0000
26	15	0.00022	0.012	0.00005	0.0027
26	5	0.00030	0.020	0.00008	0.0051
26	1	0.00028	0.017	0.00004	0.0026
26	0.1	0.00023	0.014	0.00003	0.0020
54	100	0.00006	0.003	0.00002	0.0010
54	50	0.00003	0.002	0.00001	0.0004
54	30	0.00005	0.003	0.00000	0.0000
54	15	0.00001	0.001	0.00000	0.0001
54	5	nd	nd	nd	nd
54	1	0.00007	0.004	0.00002	0.0009
54	0.1	0.00006	0.003	0.00001	0.0006
61	100	0.00017	0.010	0.00004	0.0023
61	50	0.00012	0.007	0.00002	0.0014
61	30	0.00015	0.009	0.00001	0.0007
61	15	0.00012	0.008	0.00002	0.0017
61	5	0.00011	0.007	0.00002	0.0010
61	1	0.00009	0.005	0.00001	0.0005
61	0.1	0.00014	0.008	0.00000	0.0000
75	100	0.00009	0.007	0.00002	0.0013
75	50	0.00007	0.006	0.00000	0.0000
75	30	0.00011	0.008	0.00001	0.0008
75	15	0.00003	0.002	0.00000	0.0002
75	5	0.00004	0.004	0.00001	0.0006
75	1	0.00003	0.003	0.00000	0.0004
75	0.1	0.00006	0.004	0.00000	0.0000
79	100	0.00008	0.001	0.00001	0.0001
79	50	0.00009	0.006	0.00000	0.0002
79	30	0.00006	0.000	0.00001	0.0001
79	15	0.00006	0.000	0.00001	0.0000
79	5	0.00006	0.000	0.00001	0.0001
79	1	0.00004	0.000	0.00001	0.0000
79	0.1	0.00005	0.000	0.00001	0.0001

C-4. Total nitrate uptake and per cent release of total and LMW DON from RSP²-95.

Station No.	Irradiance (μ)	Depth (m)	Total N Uptake (μg N l ⁻¹ h ⁻¹)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
3	100	0	0.13	7.6	1.3	17.0
3	50	3	0.17	7.6	0.0	0.0
3	30	5	0.13	10.1	1.5	14.7
3	15	8	0.21	5.3	0.4	6.9
3	5	13	0.08	10.0	1.4	13.9
3	1	20	0.03	34.5	0.0	0.0
3	0.1	30	0.01	72.4	7.8	10.8
5	100	0	0.38	4.6	0.6	12.0
5	50	3	0.44	4.6	0.7	15.1
5	30	5	0.37	3.3	0.0	0.0
5	15	8	0.24	7.1	1.8	24.7
5	5	13	0.19	5.6	0.6	10.9
5	1	20	nd	nd	nd	nd
5	0.1	30	0.02	53.7	8.8	16.4
14	100	0	0.05	34.3	7.0	20.5
14	50	0	0.07	28.9	0.0	0.0
14	30	3	0.07	21.5	3.1	14.5
14	15	3	0.07	26.8	1.0	3.7
14	5	5	0.03	59.5	17.8	29.9
14	1	8	nd	nd	nd	12.4
14	0.1	11	0.02	97.7	0.0	0.0
20	100	0	0.21	8.2	1.0	12.1
20	50	3	0.34	2.7	0.8	29.1
20	30	5	0.31	4.5	0.6	12.5
20	15	7	0.24	3.9	1.0	26.1

C-4. cont.

Station No.	Irradiance (%)	Depth (m)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
20	5	11	0.19	5.8	0.7	11.8
20	1	18	0.05	25.1	0.0	0.0
20	0.1	26	0.03	22.2	4.7	20.9
22	100	0	0.52	3.7	0.5	15.0
22	50	3	0.60	3.7	0.1	3.4
22	30	5	0.55	3.6	0.8	23.0
22	15	8	0.81	2.8	0.0	0.0
22	5	13	0.65	2.3	0.6	25.1
22	1	20	0.44	6.3	0.8	12.0
22	0.1	30	0.04	50.8	10.0	19.8
26	100	0	0.29	6.2	0.0	0.0
26	50	4	0.34	7.0	2.0	28.8
26	30	7	0.13	16.5	0.0	0.0
26	15	10	0.13	9.3	2.0	21.5
26	5	16	0.15	12.8	3.3	25.6
26	1	25	0.07	23.2	3.6	15.7
26	0.1	38	0.04	39.1	5.7	14.7
54	100	0	0.02	15.5	5.7	37.1
54	50	4	0.02	8.3	1.7	20.1
54	30	7	nd	nd	nd	nd
54	15	11	0.03	1.6	0.4	22.5
54	5	18	nd	nd	nd	nd
54	1	28	0.01	32.4	7.5	23.2
54	0.1	42	nd	nd	nd	nd
61	100	0	0.32	3.1	0.7	22.7

C-4. cont.

Station No.	Irradiance (%)	Depth (m)	Total N Uptake ($\mu\text{g N l}^{-1} \text{ h}^{-1}$)	% Release in Total DON	% Release in LMW DON	% LWM DON in Total DON Release
61	50	3	0.38	1.9	0.4	19.6
61	30	4	0.41	2.3	0.2	7.8
61	15	7	0.26	3.3	0.6	19.5
61	5	11	0.19	3.9	0.5	13.7
61	1	18	0.04	15.2	1.5	10.0
61	0.1	26	nd	nd	nd	0.0
75	100	0	0.39	1.8	0.3	18.4
75	50	5	0.68	1.0	0.0	0.0
75	30	8	0.59	1.4	0.1	9.5
75	15	13	0.47	0.5	0.0	7.4
75	5	20	0.60	0.6	0.1	15.4
75	1	31	0.11	2.4	0.4	15.9
75	0.1	47	0.02	24.1	0.0	0.0
79	100	0	0.34	0.2	0.0	15.8
79	50	8	0.89	0.6	0.0	3.3
79	30	13	0.60	0.1	0.0	22.8
79	15	22	0.64	0.1	0.0	9.7
79	5	34	1.06	0.0	0.0	15.3
79	1	53	0.05	0.5	0.1	14.0
79	0.1	78	0.10	0.3	0.1	27.1
Mean			0.34	8.1	1.3	14.8

VITA

Shuhua Hu was born in Shandong, China on September 21, 1967. He attended primary and secondary schools in Shandong, and graduated from the Second High School of Railroad Region, Lanzhou, China in July 1985. The following September, he entered the Lanzhou University in Lanzhou and graduated with honors in July 1989 with a Bachelor of Science degree in Ecology and Environmental Biology. In September 1989, he began work towards a Master of Science degree in the Graduate School of Lanzhou University. He received his degree in June 1992. In August 1993, he began graduate studies in the Botany Department at the University of Tennessee, Knoxville, working under a graduate research assistantship until receiving a Master of Science degree in December 1996.