AN ABSTRACT OF THE THESIS OF

Wendy Anderson for the degree of Master of Science in Horticulture presented on September 30, 1986.

Title: Effects of Cultural Practices on the Yield and Vitamin C Content of Broccoli

Abstract approved: ____________________
Harry J. Mack

Total yield, spear and stalk weight, and ascorbic acid values of spears and stalks were not affected by three nitrogen fertilizer sources ($CaNO_3$, NH_4NO_3 and urea). Broccoli spears stored at 4.4°C had lower ascorbic acid contents than did spears stored at 0°C. A loss in ascorbic acid content through time occurred at both storage temperatures. The interaction of source and time on spear ascorbic acid content was significant and indicated urea was different from $CaNO_3$ and NH_4NO_3 at two sampling times. Variations in ascorbic acid measurements indicated a possible breakdown and synthesis of ascorbic acid at different points in the storage cycle.

Nitrogen source and storage time significantly affected the respiration (mg CO_2/hr/kg) levels measured at 0°C with higher respiration levels associated with the urea fertilizer. Broccoli stored at 0°C had significantly lower respiration levels (38-72 mg CO_2/hr/kg) than did broccoli stored at 4.4°C (60-75 mg CO_2/hr/kg).

Yields of 'Gem' broccoli were not affected by the three irrigations (M1 irrigated at 0.25 MPa; M2 at 0.06-0.07 MPa; M3 irrigated three times per week) or two plant density treatments of the second field experiment. The closer plant spacing (45.7 cm x 30.5 cm) resulted in 67,078 heads per hectare with an average head weight of 104 g. while the wider plant spacing (91.4 cm x 45.7 cm) resulted in significantly fewer heads per hectare (22,736) and average head weight of 284 grams. A lower incidence of hollow stem and bractiness was associated with the higher density.

Ascorbic acid levels of spears and stalks were not affected by irrigation treatments. Spears and stalks of the higher density planting had higher ascorbic acid levels than did broccoli of the lower density planting.

Effects of Cultural Practices on the Yield and Vitamin C Content of Broccoli

by

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EFFECTS OF CULTURAL PRACTICES ON THE YIELD AND VITAMIN C CONTENT OF BROCCOLI

INTRODUCTION

Broccoli is an important vegetable in the American diet and is being consumed at an increasing rate. It ranks first in relative nutritive value among the top forty vegetable and fruit crops according to Adams (1). The major nutrients contributed by broccoli include ascorbic acid, vitamin A, riboflavin, thiamine, calcium, phosphorus, and iron (20,61). Broccoli is grown in Oregon for fresh market and processing, about 810 ha yielding 7,990 MT with a value of three and one half million dollars. Oregon ranks third in the nation in broccoli production. Total U.S. production was over 467,000 MT in 1984 with a value of $238 million (60).

Cultural practices which may affect the yield and quantity of vitamins in vegetables are fertilizers, spacing, irrigation, and harvest date (27,28,56). The objectives of this study were to determine the effect of some specific cultural practices on the ascorbic acid content, storage life, and yield of broccoli.

REVIEW OF LITERATURE

Effects of Nitrogen Sources on Yield, Ascorbic Acid and Storability

Nitrogen rates and sources can affect growth, development, and storage of the crop. Some plants are able to utilize NO_3-N more readily than NH_4-N^+. Asparagus transplants achieved maximum growth in a nutrient solution with a nitrogen ratio of 75% NO_3- and 25% NH_4+. Growth was significantly reduced when nitrogen composition was either 100 or 75% NH_4-N^+ (47). However sweet potato yield of No. 1 roots was not influenced by three nitrogen sources according to Hammett et al (15).

Ammonium sulfate reduced concentrations and total amounts of ascorbic acid in cress seedlings. A larger depression was noted when the ammonium ion was in combination with Cl^- or SO_4^{-2} (33). Ascorbic acid levels of cress seedlings were decreased by the addition of NH_4^+ to a water plus sucrose solution (34). Somers and Kelly (57) infiltrated turnip and broccoli leaf discs with varying nutrient solutions and concluded that the ammonium ion depressed ascorbic acid levels, especially when in combination with the chloride or sulfate anion.

Experiments performed in the field have indicated that no large differences in ascorbic acid levels were found in cauliflower when nitrogen levels or sources were varied (39). Climatic factors associated with different locations or seasons exerted a greater influence on relative vitamin content than cultivar, soil type, or fertilizer application. Intensity of light tends to influence ascorbic acid more than any other factor (28). Light, temperature, and moisture affected nutrient composition more than fertilizer practices (20).

Changes in ascorbic acid content of potatoes showed two distinct phases according to Shekhar et al (54). The first phase was characterized by an increase in ascorbic acid content with an increase in growth and development, and the second was characterized by a decrease in ascorbic acid content with increasing maturity. Increasing nitrogen fertilization is known to cause a delay in maturity and thus delay the shift to the second phase.

Effects of Storage Temperature and Duration on Ascorbic Acid Concentration

A major limitation to maintaining ascorbic acid content of vegetables can be in the handling and storage of the crop where losses have ranged from 0% to 76% (12). The ascorbic acid stability is influenced by precooling, the rate of water loss, and by temperature levels during storage (38,49,51,62).

High temperatures reduce ascorbic acid concentrations while low temperatures maintain ascorbic acid levels. Cabbage lost only 11% ascorbic acid in two weeks of refrigerated storage (45). Over 40% of ascorbic acid content of asparagus, 50% in broccoli and 40% in spinach were lost in 24 hours at 21°C (19). Potato tubers stored at 5.5°C showed a marked reduction in ascorbic acid levels (54). Storage at low temperatures alters carbohydrate metabolism in tubers and thus affects ascorbic acid biosynthesis since carbohydrate and ascorbic acid metabolism are related (13).

Overview of Ascorbic Acid

Ascorbic acid, a labile vitamin, is more readily lost through handling and processing than most other constituents of foods. It is subject to leaching and is highly susceptible to chemical degradation (12,35).

This vitamin appears to be synthesized in leaves and then transported to meristematic regions in the root and shoot tip. Ascorbic acid functions in the respiratory metabolism of plants in oxidation reduction systems (26).

Ascorbic acid is a γ-lactone of a hexonic acid with an enediol structure at carbons 2 and 3. It is unstable and quickly oxidized to dehydroascorbic acid. The metabolic pathway for synthesis involves the following:

UDP-D-glucose + 2 NAD^+ + H_2O --> UDP-D-glucuronic acid + 2 NADH + $2H^+$

D-glucuronic acid $\xrightarrow{\text{Reduced}}$ L-gulonic acid $\xrightarrow{\text{lactonizes}}$ L-gulonolactone $\xrightarrow{\text{oxidized}}$ L-ascorbic acid (2,25,29).

External factors known to affect the biosynthesis of ascorbic acid are: light intensity (16,17,48); latitude (18); salts (34); nitrogen supply; temperature (11,41,45); and possibly molybdenum (21,33).

Internal factors affecting the biosynthesis appear to be continued production of hexose sugars, the presence of oxygen, and the maintenance of reduced phosphopyridine nucleotides by active reducing systems in the tissue (26).

Effects of Plant Population on Yield of Broccoli

Conventional spacings of 46 cm within rows and 91 cm between rows are representative of fresh market production of broccoli while higher populations are used in production for processing. Several changes in plant microenvironment occur when plant density is changed in the field. Light intensity per plant decreases with closer spacings due to shading (63). Competition for fertilizer and water is increased with higher plant populations.

Increasing plant population changes the morphology of broccoli. Large spacings result in stocky plants with large central inflorescences while closer spacings result in tall plants with small heads. A three year experiment showed that the size of center heads and yield of shoots per plant decreased as the spacing of broccoli plants in single rows, 106.7 cm apart, was reduced by 15.2 cm intervals from 91.4 cm to 45.7 cm. The greater number of plants at the closer spacings increased the total usable yield (36). A decrease in head diameter was found with high densities and the reverse with low densities. Differences in stem diameter ranged from 2.03 cm at 10.2 cm to 2.5 cm at a 30.5 cm spacing, an increase of 20%. Floret diameter increased from 5.1 cm at 10.2 cm spacing to 5.8 cm at 30.5 cm spacing; an increase of 13%.

A larger percentage of poor quality heads due to shading are developed with spacings of 10.2 cm to 15.2 cm (63). Overmature spears decreased from 16% in low populations to 9% in higher populations (8). Hollow stem, bractiness, and axillary bud development all became less pronounced as population was increased while uniformity of buds and head color increased (58). Cutcliffe (9,10) found an increase in the percentage of hollow stem as distance between plants increased and the rate of nitrogen application increased. 'Gem' appeared to be the most susceptible cultivar of nine cultivars tested. Hollow stem is undesirable for preparation of the frozen product as discoloring can occur in processing.

Crop maturity may be delayed by increased plant populations. Single harvest yields (important in processing) increased at a calculated rate of 335 kg/ha/day during the three to four day period between first and second harvest dates. The optimum plant population for 'Primo' or 'Gem Hybrid' appeared to be about 62,000 plants/ha (40 x 40 cm)

(8,42). Once-over harvest yields of broccoli spears increased as plant density increased (8,42,63). Chung (4) found it more appropriate to harvest by machine at a time of optimum yield even though there was an average yield reduction of 10% compared with maximum total yield. The benefits are that less waste material is harvested due to the absence of overmature plants.

Chung (4,5) also found that an asymptotic yield-density relationship occurred with broccoli which indicates that spear yield approaches asymptote at a low plant density (20 pl/m^2) and consequently similar yields could be obtained over a wide range of plant densities. No significant effect of plant density on the harvest index was found by Salter at densities greater than 20 plants/m^2 (50). The densities studied varied from 2-100 plants/m^2. Yield was relatively insensitive to density above 20 plants/m^2 but mean head size decreased with increasing density.

Differential cultivar responses have also been noted in conjunction with plant population changes (10). 'Rex' had optimum production at 54 plants/m^2 vs. 'Harvester's' optimum at 113 plants/m^2 (59).

Effects of Irrigation Levels on Yield and Ascorbic Acid Concentration of Vegetables

Irrigation levels affect plant development, maturity date of the crop, yield, and quality of the harvestable portion. Adequate irrigation is necessary to produce maximum yields of high market quality (36). Different crops respond in conflicting ways to changing soil moisture levels. Somers and Beeson (56) reported that irrigation increased the ascorbic acid content of potatoes. Additional work indicated that turnip greens grown in different southern locations had the highest ascorbic acid levels on a fresh weight basis at the locales with the least precipitation. Janes (27) discovered higher values of ascorbic acid on non-irrigated plots of snap beans than on the irrigated plots. The trend was the same whether expressed on a dry or fresh weight basis. Turnip greens grown by Hunter et al (24) at three soil moisture levels yielded more Vitamin C under high moisture tension. Higher soil moisture tensions tended to increase the concentration of ascorbic acid when the ascorbic acid content was expressed on a unit fresh weight basis and to decrease when expressed on a dry weight basis.

Irrigation vs. no irrigation on broccoli inflorescenses resulted in no significant effect on ascorbic acid levels; however there were differences in yield. Irrigated plots yielded almost twice as much as non-irrigated plots (36). Beverly, et al (3) found that average total top weight and average head weight of broccoli were greater when furrow irrigation equaled evapotranspiration than when irrigation was 30% greater. An increase in growth rate occurs in broccoli as the vegetative buds undergo transition to the reproductive stage and as the heads near market size (32). Irrigations at this time had a significant effect on the yield of the plant. Singh and Alderfer (55) found broccoli most sensitive to water stress during head formation and enlargement but water stress imposed at any period of growth reduced yield.

Maurer (37) evaluated the effects of five different soil water regimes and determined that yield of marketable heads was least in the dry and wet-dry regimes and intermediate in the medium regime. Plants exposed to water stress beginning at head formation or exposed to stress throughout the growing period suffered yield decreases. Some plant species can recover from a water stress period imposed during a non-critical period while some require adequate supplies of soil water throughout their growth (55). Broccoli fits into the second category, requiring adequate water throughout the growing season.

MATERIALS AND METHODS

Field studies were conducted in the summer of 1980 at the Oregon State University Vegetable Research Farm, Corvallis. The soil is a Chehalis silty clay loam with a water holding capacity of about 6.4 cm per 0-30 cm depth. The experimental area had been in various research plots for over twenty years but there were no fertilizer differentials during the past three years.

A cover crop of winter wheat was plowed down in the spring. After plowing, the area was disc-harrowed several times to produce a fine seed bed. Trifluralin, a preplant herbicide, and fonofos, an insecticide for symphyllans and root maggots, was broadcast and incorporated in the last two disc-harrowings. Insecticides applied on the fertilizer source plots during the growing season included diazinon (dust), carbaryl (spray), fonofos drench, and a mix of carbaryl and Dipel (spray). Insecticides used on the spacing-irrigation study included carbaryl (spray), diazinon (drench), Dipel (spray), and a soil application of oxydemetonmethyl.

Weeding after seedling emergence was performed by hand hoeing within the plots and by tractor cultivating around the outer perimeters. Plots were thinned when the plants were 15-23 cm in height.

Temperature and rainfall data during the growing season are given in Appendix, Table 2. Yield data were collected by cutting center heads at a length of 13 cm from the top of the spears and then taking fresh weights on those samples.

Nitrogen Fertilizer Source Study

Three nitrogen sources, calcium nitrate (15.5% N), ammonium nitrate (34% N), and urea (46% N), were evaluated in a completely randomized design with six replications.

A broadcast application of N-P-K, made preplanting and incorporated by disc harrowing, supplied 135 kg N, 177 kg P and 112 kg K/ha. 'Gem' broccoli was direct-seeded with a Planet Jr. in 45.7 cm rows on May 22 and emergence was on June 2. The plants were thinned after one months' growth to a within-row spacing of 30.5 cm (approximately 71,740 plants/ha). A sidedressing of each nitrogen source was applied at the rate of 56 kg N/ha on July 8, one month after seedling emergence.

Plants were harvested in all plots on August 4 and 7. Ten center heads per plot were cut as a representative sample for each harvest. The heads were then cut to a standard fresh market length of 13 cm. Total fresh weight was taken, then heads were separated into spears and stalks and weighed. Spears were defined as that portion of the head beginning at the point of stem branching and continuing up to the top of the spears. The stalk was defined as that portion of the stem beginning at the point of stem branching and continuing down to the stem end. Amount of head rot was determined by a visual and olfactory observation of heads sampled for yield. Additionally, samples of four heads per plot were harvested on August 5, and these were placed in perforated plastic bags (two heads per bag) for storage at $0^{o}C$ and $4.4^{o}C$ room for a two week period for ascorbic acid determinations. The ascorbic acid levels were determined every three days.

Sample Preparation and Analysis for Ascorbic Acid

Ten gram samples of broccoli were cut up with new stainless steel razor blades and placed into 50.0 ml metaphosphoric-acetic acid extracting solution. A Virtis mixer was used to grind samples for two minutes. Ground samples were gravity filtered through glass wool into 50 ml volumetric flasks. The metaphosphoric-acetic acid solution was again added to flasks to a 50 ml volume. Two milliliter samples were taken from these flasks and placed into a small beaker with a magnetic stirring bar. Five milliliters of the reagent acid solution were then added. The sample was titrated with an indophenol indicator solution until a pink color remained for at least one minute. A standard curve using a standard ascorbic acid solution was prepared each day samples were run (23).

Storage Study (Fertilizer Experiment)

Four broccoli heads per replication from the fertilizer plots were harvested on August 5, cut to a length of 13 cm, and placed in 22.7 liter plastic buckets in two cold storage rooms at $0^{o}C$ and $4.4^{o}C$ for 14 days. Buckets were sealed and hooked up to the flowboard system. Flow rates were maintained at approximately 180 ml/min. in an apparatus similar to that of Claypool and Keefer (6). Carbon dioxide was measured daily by the colorimetric method (45).

Irrigation and Spacing Study

Three irrigation treatments and two plant spacings were included in a completely randomized design with three replications. Each irrigation plot was 6.1 m wide by 6.1 m long with an overhead sprinkler at each corner. Plots were separated by 20 m of bare soil so that irrigation of one plot would not influence other plots. Irrigation treatments were as follows (1) M1 - irrigation when approximately 65-70% of available water was depleted at 30.5 cm depth, 0.25 MPa soil water potential. (2) M2 - irrigation when approximately 40-45% of available water was depleted at 30.5 cm depth, 0.06 to 0.07 MPa soil water potential and (3) M3 - frequent irrigation (irrigation three times a week). Soil water potential was measured by gypsum electrical resistance soil moisture blocks placed in the seeded row (53). These were at 25, 30.5, and 45.8 cm depths and read every other day, but only the measurement at 30.5 cm was used for irrigation scheduling (31). Enough water was applied at each irrigation to return soil to field capacity. Number of irrigations, amount of water applied and other observations are shown in Appendix, Table 1.

A broadcast application of fertilizer was made before planting and incorporated by disc-harrowing to supply approximately 180 kg N, 236 kg P and 149 kg K/ha. 'Gem' broccoli was seeded on June 20 at two row spacings of 91.4 cm and 45.7 cm. Plants were thinned one month after seeding to two densities: (1) D1 - 91.4 cm between rows and plants 45.7 cm within rows; 23,940 plants/ha and (2) D2 - 45.7 cm between rows and plants 30.5 cm within rows; 71,740 plants /ha. Only the D2 density was included in the M1 treatment. The five treatment combinations were M1D2, M2D1, M2D2, M3D1 and M3D2, replicated three times for a total of fifteen plots. All plots were irrigated at ten to fourteen day intervals until the stand was established and plants had attained a pre-heading size. Differential irrigation treatments were initiated on July 28 and continued to harvest.

Each plot was harvested on August 29 and September 2 to obtain the maximum yield of center heads at processing maturity. Three central rows of 91.4 cm rows and six central rows of 45.7 cm rows were harvested for a total area of 11.7 m^2. One meter at beginning and end of rows was left as border and not harvested. Heads were trimmed to a standard length of 13 cm and total fresh weight, spear weight, stalk weight, number of heads and average head weight were recorded. Amount of head rot was determined by visual and olfactory observation of heads sampled. Two heads per plot were removed from the larger samples at each harvest date and analyzed for ascorbic acid concentration of spears and stalks.

Experiments were analyzed as completely randomized designs using a multivariate ANOVA. The Newman Keuls multiple comparison of means was utilized to discern differences of the means obtained from the nitrogen fertilizer source experiment. Linear comparisons were used in the spacing and irrigation analysis to obtain intended comparisons of moisture and density factors.

RESULTS AND DISCUSSION

Effect of Nitrogen Fertilizer Sources on Yield

No significant effects of nitrogen fertilizer sources were found on broccoli yield, on percent spear or on percent stalk (Table 1). These findings are in agreement with those of Hammett et al (15) who found that sweet potato yield was not affected by different nitrogen fertilizer sources.

Effect of Nitrogen Fertilizer Sources on Storage of Broccoli at 0°C and at 4.4°C

1) Ascorbic Acid Levels of Spears

No significant effect of nitrogen source was found on spear ascorbic acid levels at any time during storage at 0°C or at 4.4°C (Figures 1 and 2). These results are in accord with the work on nitrogen sources and ascorbic acid content by other researchers (19,28) who found that light, temperature and moisture affected nutrient composition more than fertilizer practices.

A Newman Keuls multiple comparison test of means revealed the significance of sampling time exhibited in Figure 3. An overall loss occurs through time at both storage temperatures similar to that found by Fennema and others (12,43). Significant differences between sampling times is an example of the variation noted by some re-

Table 1. Influence of N fertilizer sources on yield of broccoli

N Source	YIELD in MT/ha Total	Spears	Stalks	% Floret	% Stalk
$CaNO_3$	9.4[y]	4.5	4.9	48.2	51.8
NH_4NO_3	9.8	4.6	5.2	47.0	53.0
Urea	9.7	4.6	5.1	47.8	52.2

[y]No significant effect of nitrogen fertilizer sources.

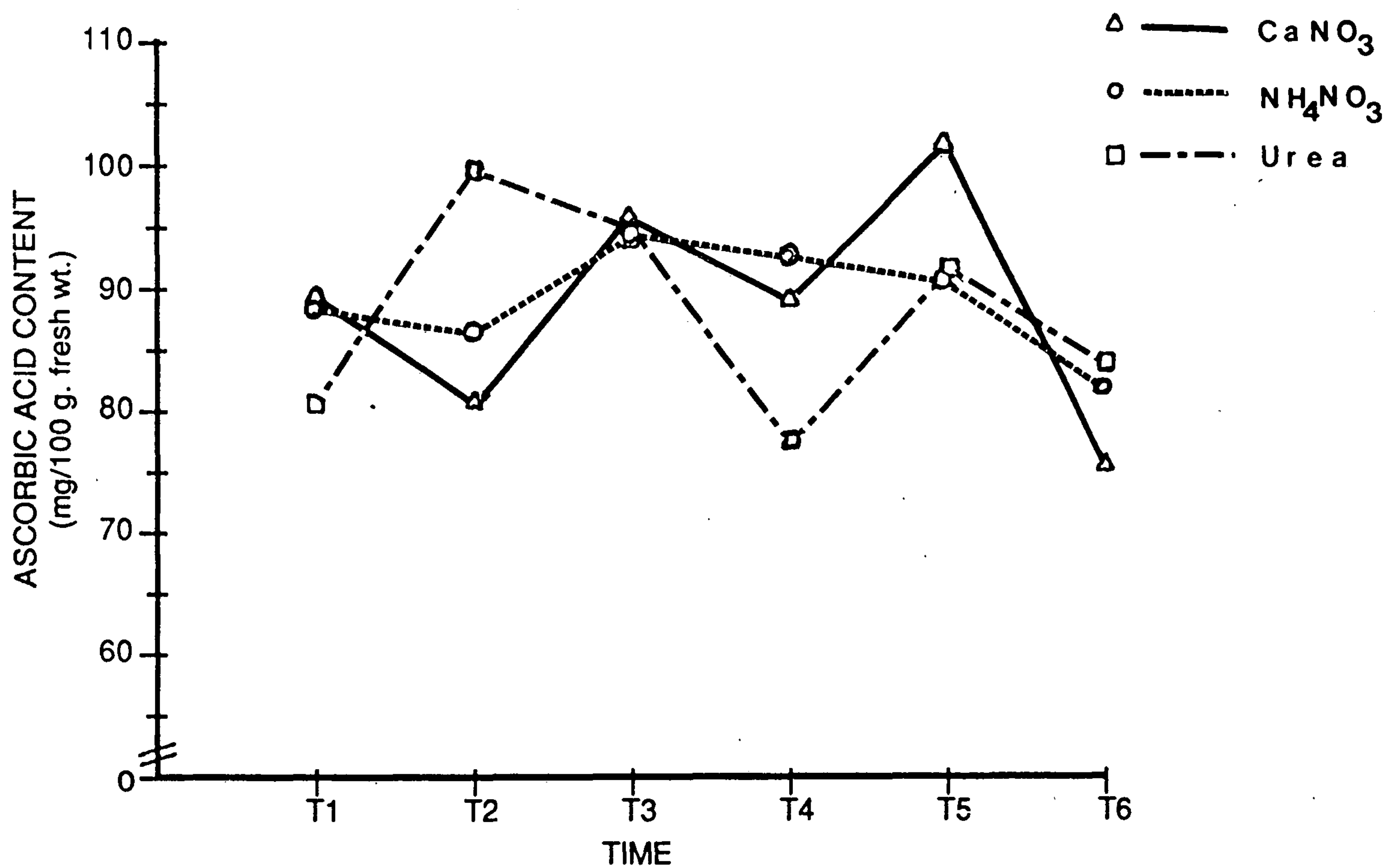

Figure 1. Effects of nitrogen sources and sampling time in storage on ascorbic acid content of spears at 0°C.

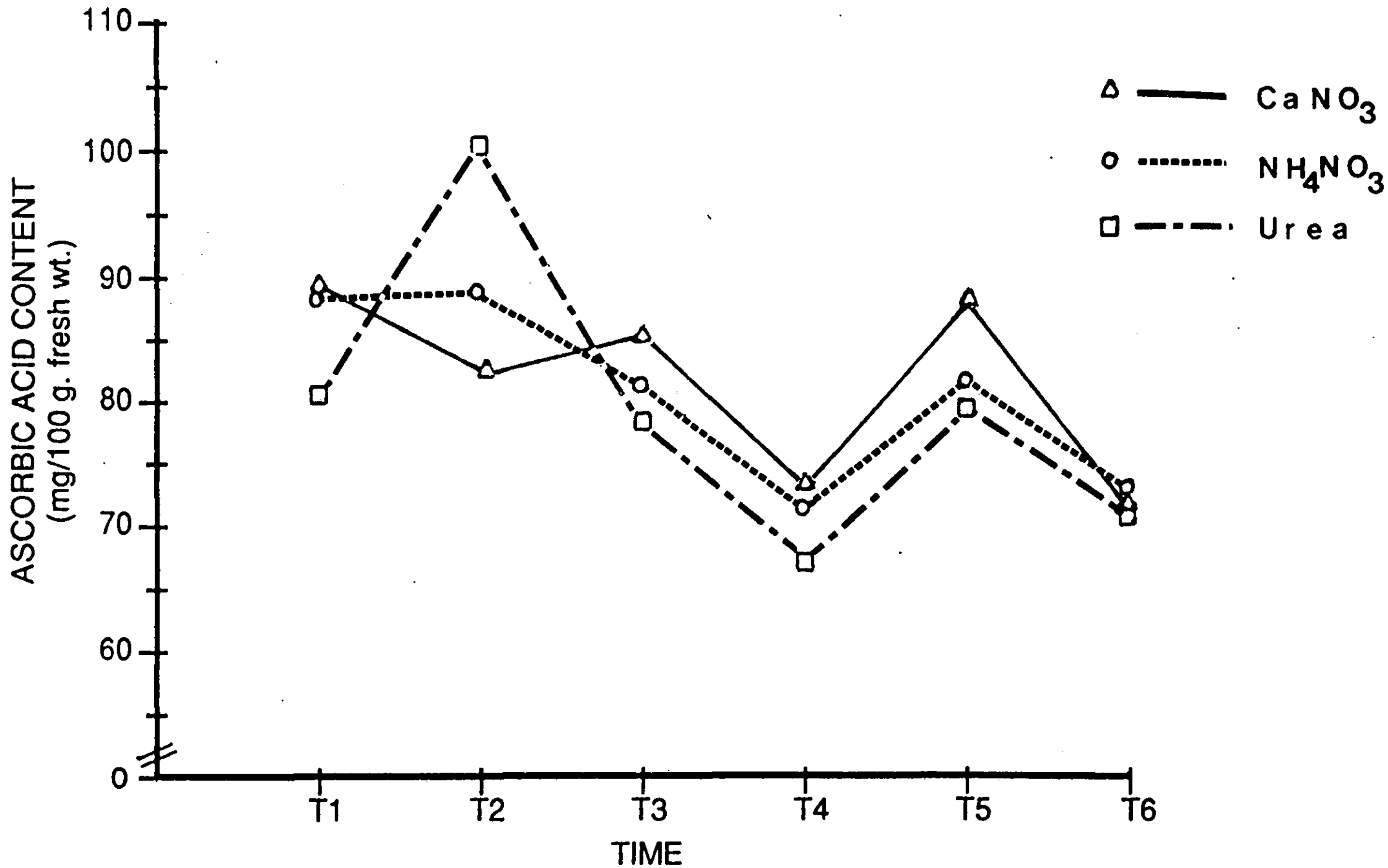

Figure 2. Effects of nitrogen sources and sampling time in storage on ascorbic acid content of spears at 4.4°C.

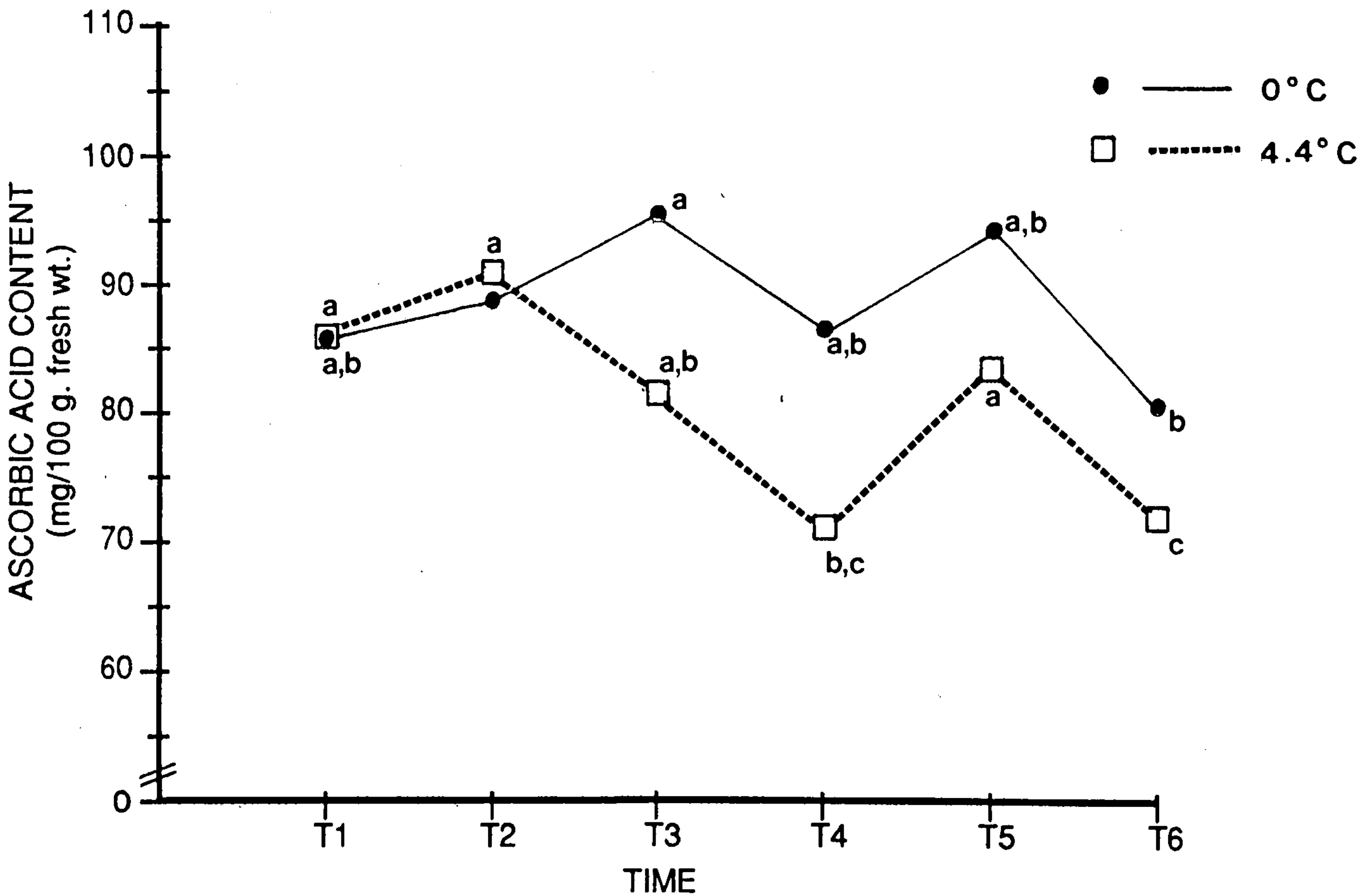

Figure 3. Effects of sampling time in storage on ascorbic acid content of spears at 0°C and 4.4°C with nitrogen sources pooled. Values represent 9 samples per mean. Mean separation of each storage temperature between analysis times with Newman Keul's multiple range test, 0.05 level.

searchers (40,43). The magnitude of the difference is dependent on the vegetable under study. Corn on the cob (blanched and frozen) exhibited variation from initial levels of 12.0 mg/100 g fresh weight to 8.7 mg at 6 weeks of storage to 12.2 mg ascorbic acid at 12 weeks of frozen storage (43). Potatoes in storage had 1.5 to 2 times greater ascorbic acid content after 8 months storage than at 4 or 12 months (52). Broccoli ascorbic acid values had a range of 23 mg/100 g fresh weight in some cases (Unpublished data, 1978, Richardson).

The interaction of nitrogen source and time was non-significant. A separate ANOVA was prepared to analyze the effect of temperature, source and time on the ascorbic acid levels of the spears. Temperature (Figure 3) significantly affected the ascorbic acid values of broccoli spears. Broccoli stored at $0^{o}C$ had a mean ascorbic acid level of 88.6 mg as compared to a mean of 80.8 mg for broccoli stored at $4.4^{o}C$ (all sampling times pooled). These values support previous work which indicated higher storage temperatures result in lower ascorbic acid levels while cooler storage temperatures maintain higher ascorbic acid levels (12,19,54). Detrimental enzymatic changes can occur faster at higher temperatures (14). The oxidative reactions are proceeding at a higher rate which could mean ascorbic acid is being oxidized faster at the warmer storage temperature.

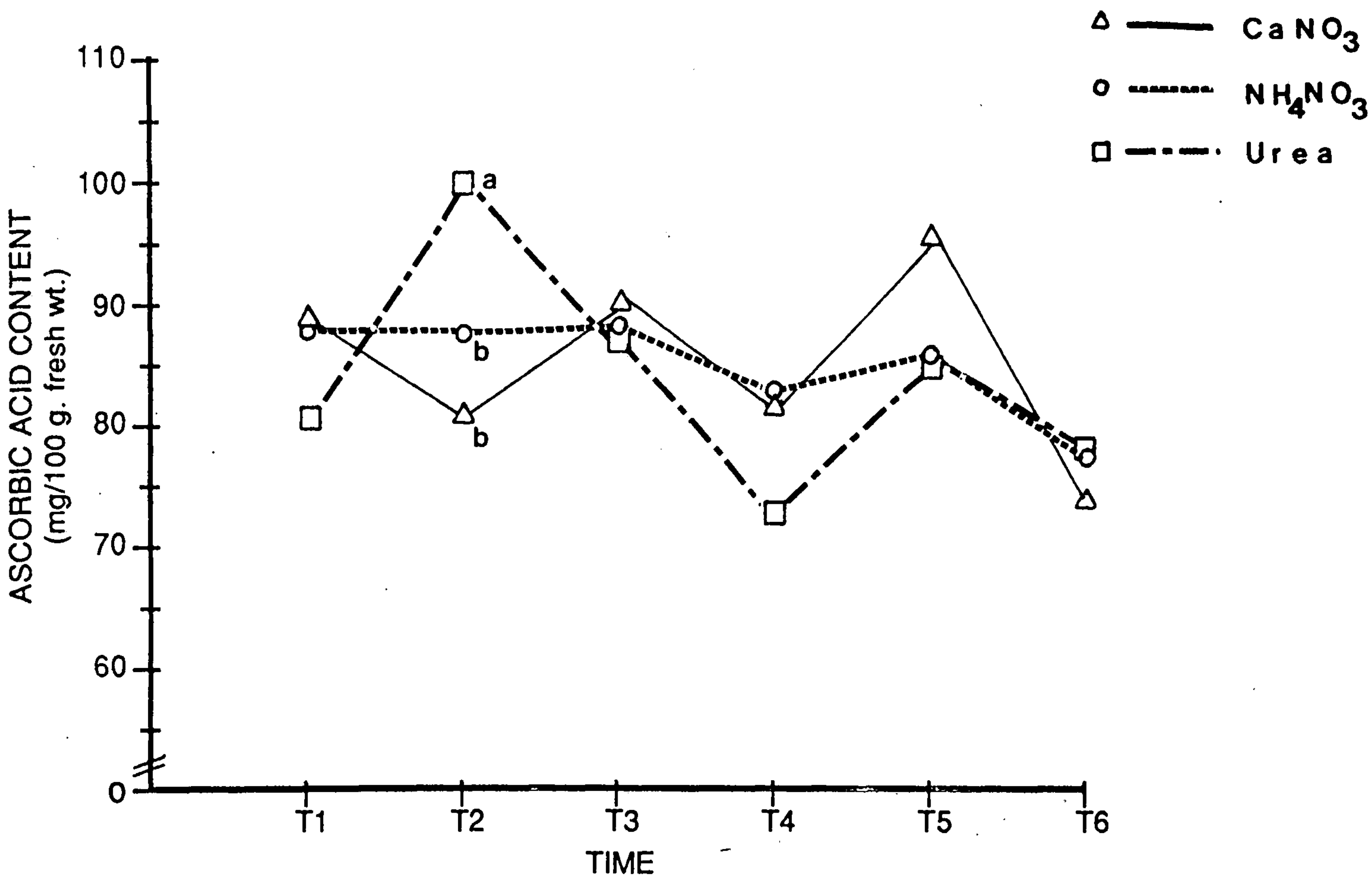

Figure 4. Effects of nitrogen sources and sampling time in storage on ascorbic acid content of spears with storage temperature pooled. Values represent 6 samples per mean. Mean separation vertically between sources at each sampling time with Newman Keul's multiple range test, 0.05 level.

The interaction of source and time (Figure 4) proved significant with the Newman Keuls multiple comparison test when results from the two storage temperatures are combined. Broccoli from the $CaNO_3$ and NH_4NO_3 sources, with ascorbic acid values of 81.3 and 87.6 mg, respectively, are different from the urea value of 100.0 mg ascorbic acid at Time 2. However, broccoli ascorbic acid values from the urea fertilizer plots tend to exhibit more variation through time than values from the other two fertilizer sources. This more extreme variation could be the explanation for the difference exhibited at Time 2.

2) Ascorbic Acid Levels of Stalks

No significant effects of nitrogen source (Figures 5 and 6) or temperature (Figure 7) were found on ascorbic acid levels of stalks during storage.

The effect of time on ascorbic acid levels was significant at both storage temperatures. Ascorbic acid levels are low at Time 4 in both storage rooms and are significantly different from Time 1 and 5 in the $0^{\circ}C$ temperature and Times 1 and 6 in the $4.4^{\circ}C$ temperature (Figure 7). An overall decrease in ascorbic acid level was expected; however, the second peak of ascorbic content in broccoli stored at $4.4^{\circ}C$ was not and can possibly be explained by the variations encountered in analyses of ascorbic acid and not the effects of a higher temperature on the storage quality of the broccoli.

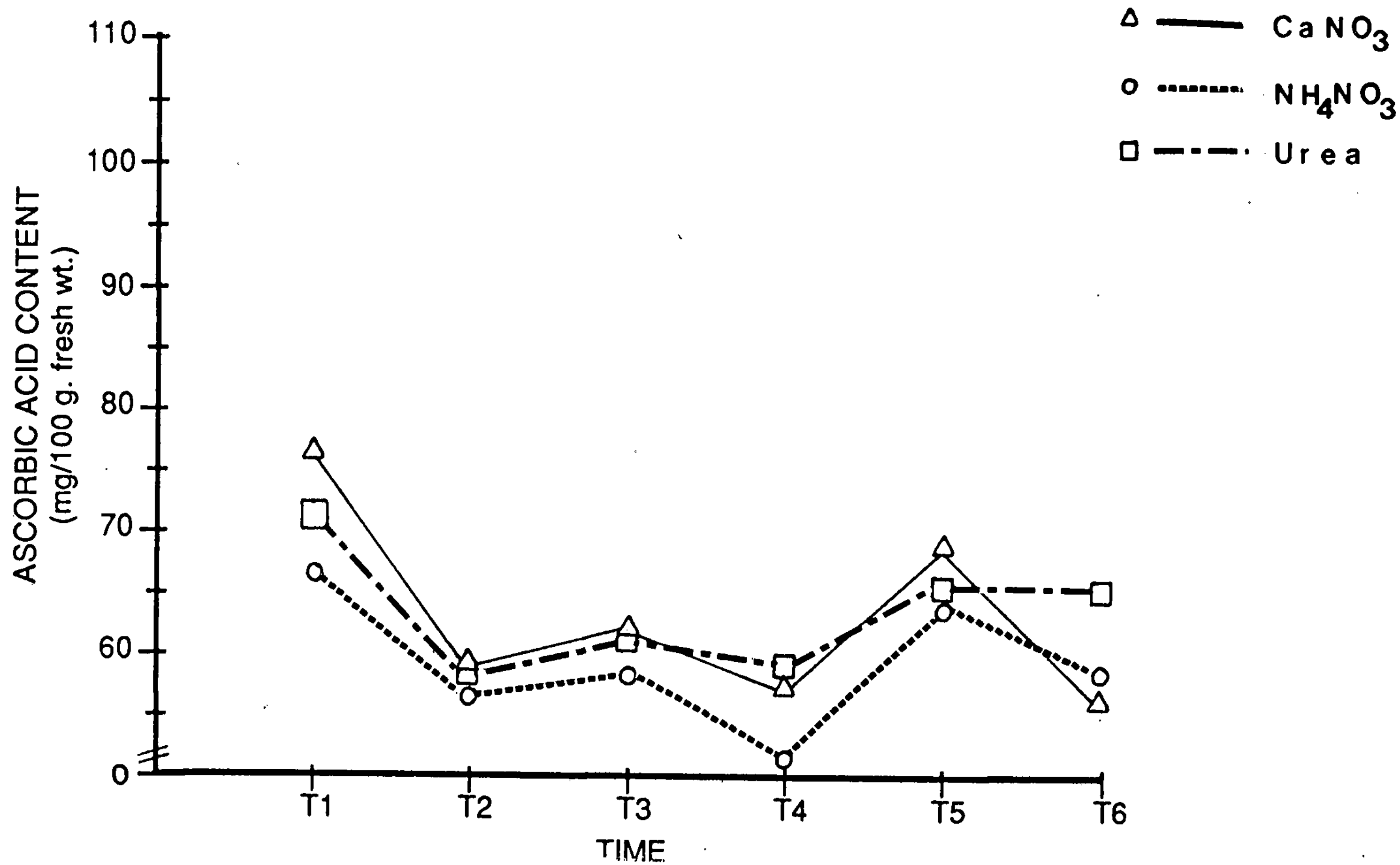

Figure 5. Effect of nitrogen sources and sampling time in storage on ascorbic acid content of stalks at 0°C.

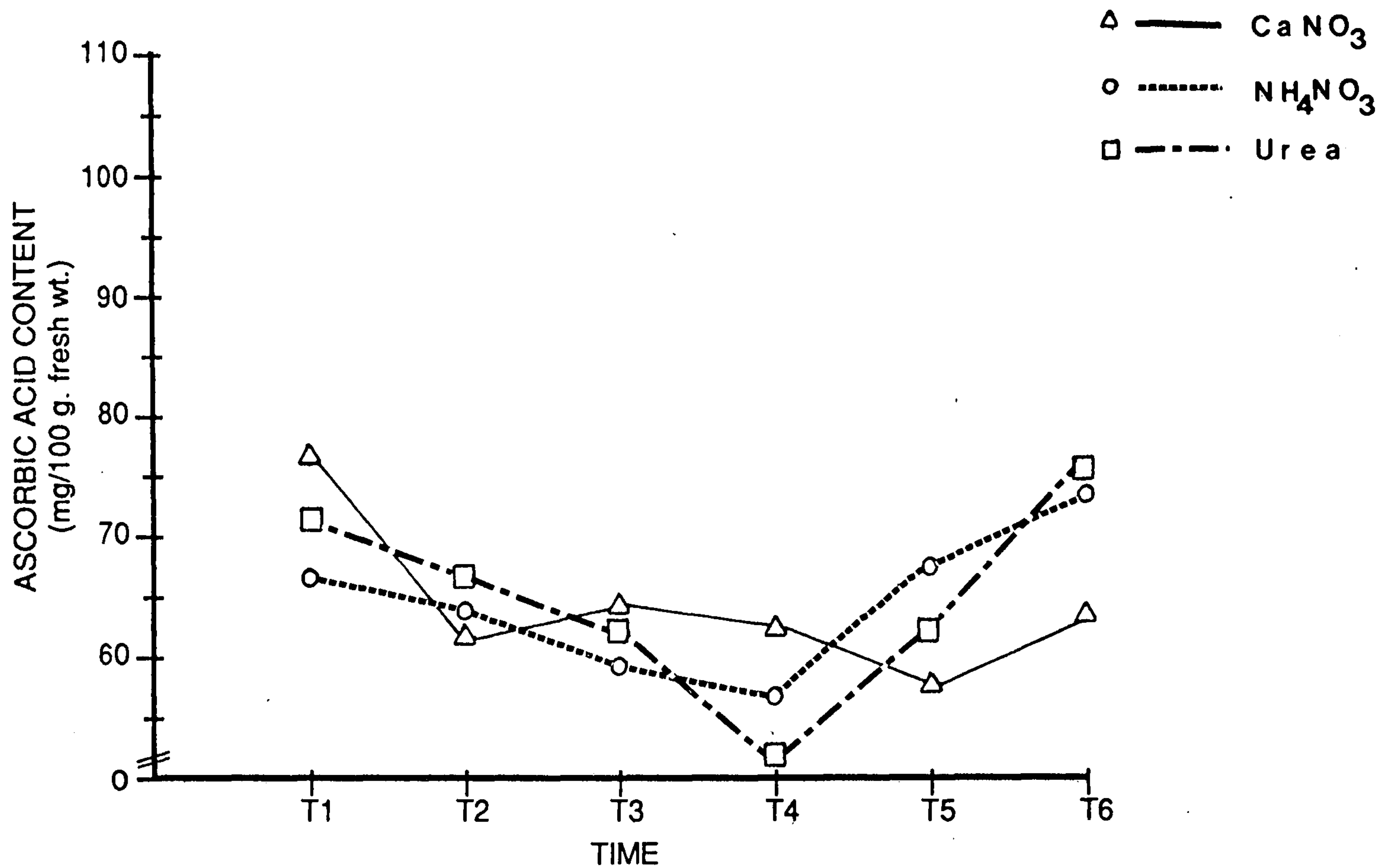

Figure 6. Effects of nitrogen sources and sampling time in storage on ascorbic acid content of stalks at 4.4°C.

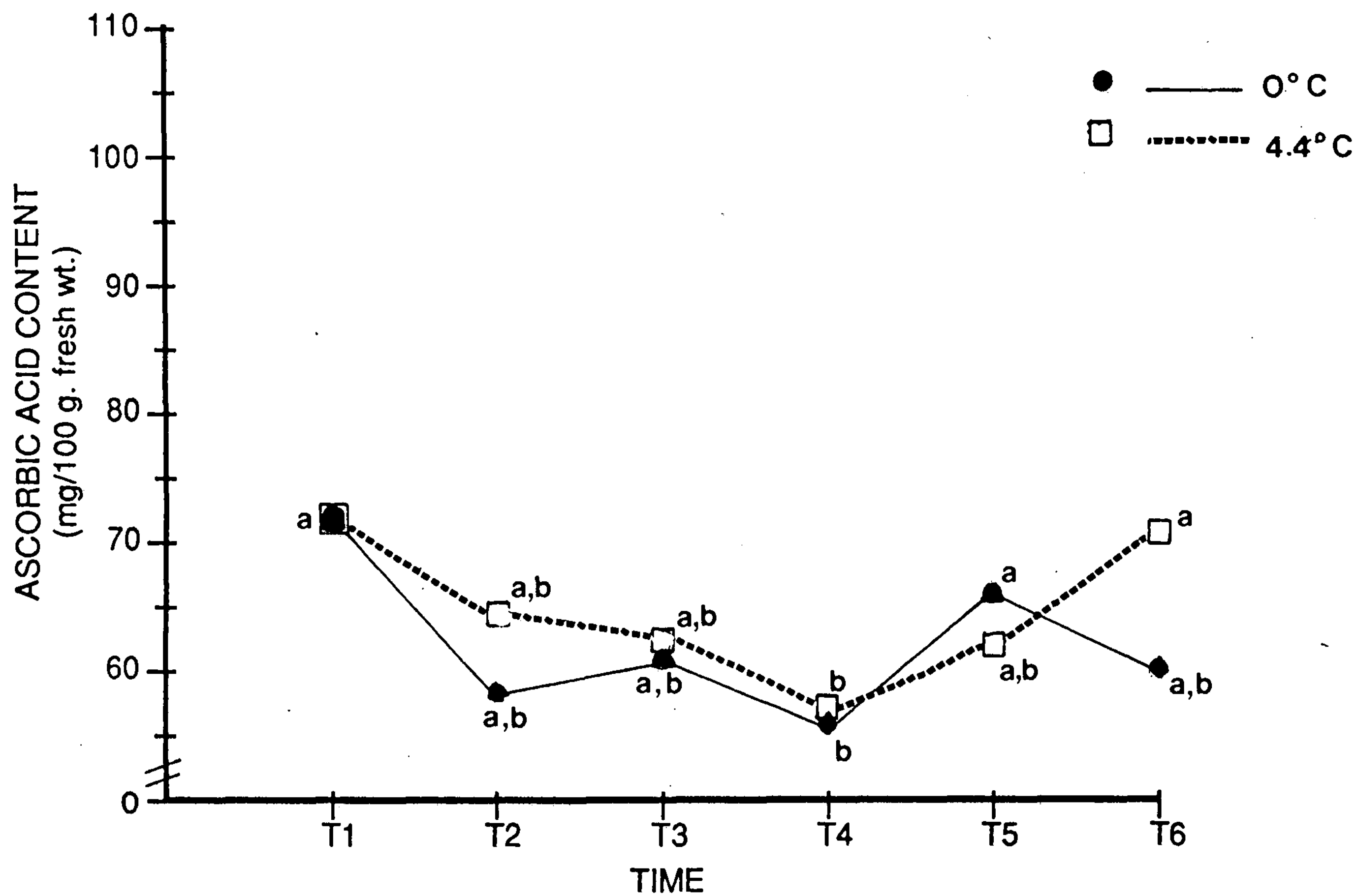

Figure 7. Effects of sampling time in storage on ascorbic acid values of stalks at 0°C and 4.4°C, with nitrogen sources pooled. Values represent 9 samples per mean. Mean separation of each storage temperature between analysis times with Newman Keul's multiple range test, 0.05 level.

Time effects also were significant when sources and temperature were pooled in a separate ANOVA (Figure 8). A multiple comparison test showed Time 1 (71.3 mg) to be different from Times 2 (61.2 mg), 3 (61.5 mg) and 4 (56.6 mg). The large decrease and then rise in ascorbic acid could possible be an example of the phenomenon noticed in other reports (43,52) where ascorbic acid values in potatoes and frozen corn decreased through time and then at some point in storage an apparent increase or regeneration of ascorbic acid occurs. Stalk ascorbic acid levels seemed to be slightly more stable than the spear ascorbic acid levels. They do not have extreme variation from one sampling time to the next. This increased stability could be attributed to the type of tissue involved. The broccoli spear is composed principally of meristematic tissue and is more sensitive to temperature and moisture changes and thus more liable to variations in ascorbic acid than stalk tissue.

The time by source interaction was not significant.

3) <u>Respiration (mg CO_2/hr/kg tissue) Levels</u>

Nitrogen fertilizer source and time both affected respiration levels of broccoli stored at $0^{o}C$ (Figure 9). The respiration levels of broccoli from the urea nitrogen source plots are typical of a senescing vegetable. Respiration levels of broccoli from the $CaNO_3$ and NH_4NO_3 fertilizer sources increase by 25 mg CO_2/hr/kg from Time 1 to

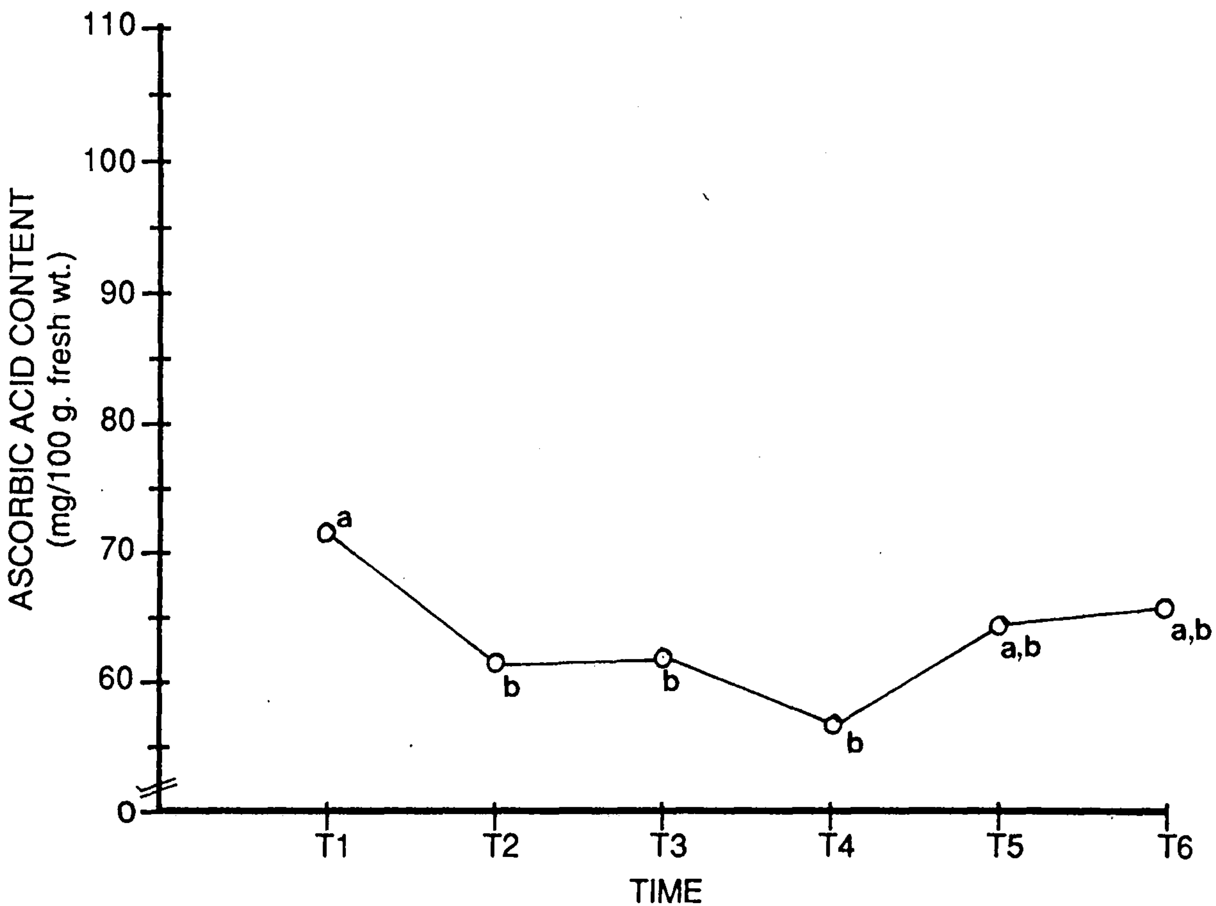

Figure 8. Effects of sampling time in storage on ascorbic acid values of stalks with nitrogen sources and storage temperatures pooled. Values represent 18 samples per mean. Mean separation between analysis times with Newman Keul's multiple range test, 0.05 level.

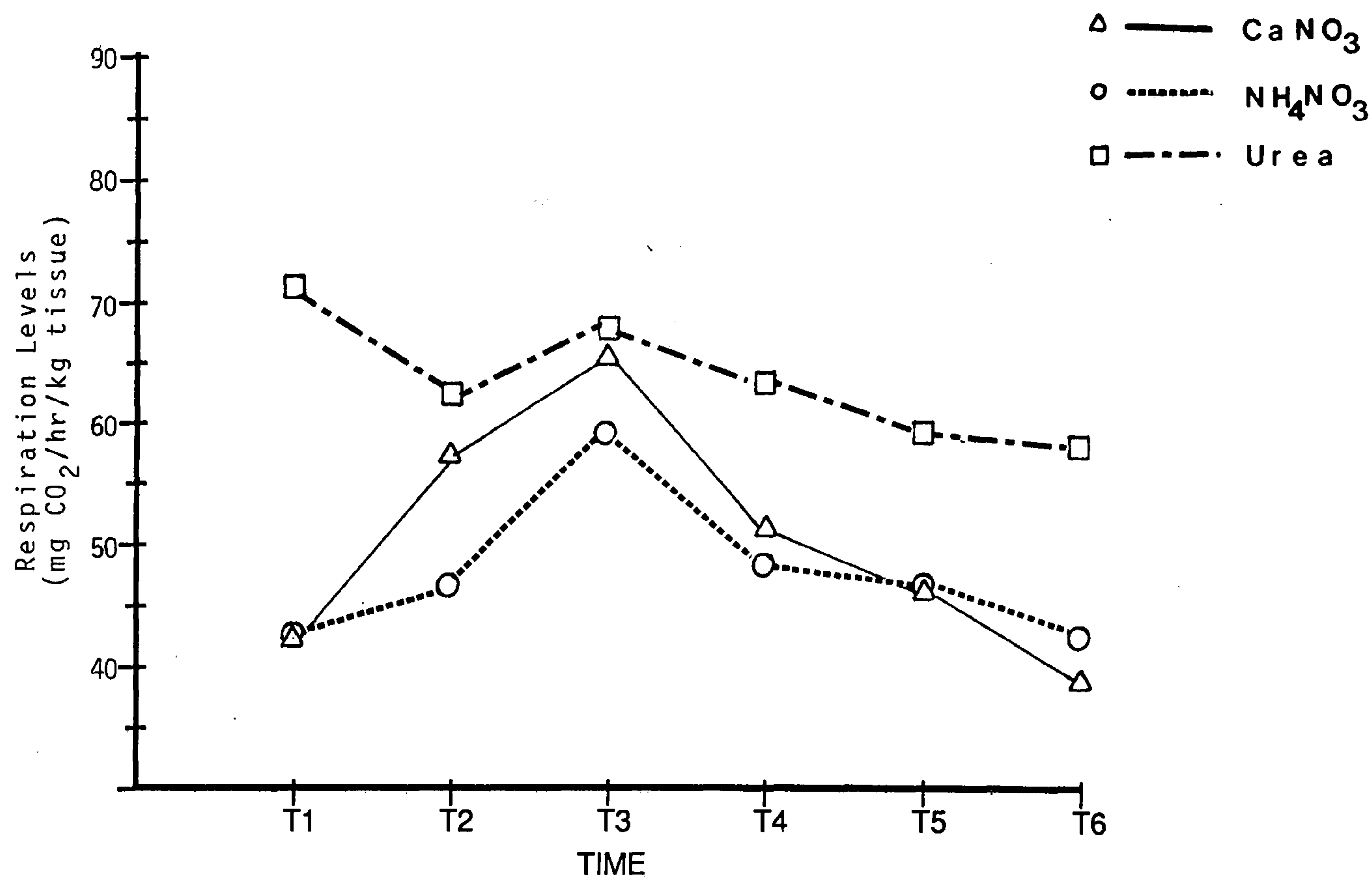

Figure 9. Effects of nitrogen sources and sampling time in storage on respiration (mg CO_2/hr/kg) levels at 0^oC. Values represent 3 replications per mean.

Time 3 and then decrease to less than 45 mg/hr by Time 6. This type of curve is more typical of a climacteric commodity and was not expected in this study. Higher respiration levels associated with the urea fertilizer could possibly support evidence from growers and cannery representatives that when urea fertilizer is used broccoli has a higher tendency to exhibit head rotting (personal communication, 1980, Leon Hubbard). Head rot caused by Erwinia carotovera found in a cannery broccoli lot, results in the rejection of that lot. A count was made of broccoli which contained head rot within all harvested samples. The very small incidence of head rot which occurred did not appear to be related to the nitrogen fertilizer source used.

Broccoli stored at 4.4°C was not significantly affected by nitrogen source, time or the interaction of the two factors (Figure 10).

When respiration values of the broccoli at 0°C storage temperature were compared to those of 4.4°C, the interaction of source and temperature, and of time and temperature were significant.

The respiration values found in the broccoli from the 4.4°C temperature range from 60-75 mg CO_2/hr/kg tissue while those of the 0°C temperature range from 38-72 mg CO_2/hr/kg tissue. Respiration values of the warmer temperature are much higher than those of the cooler storage

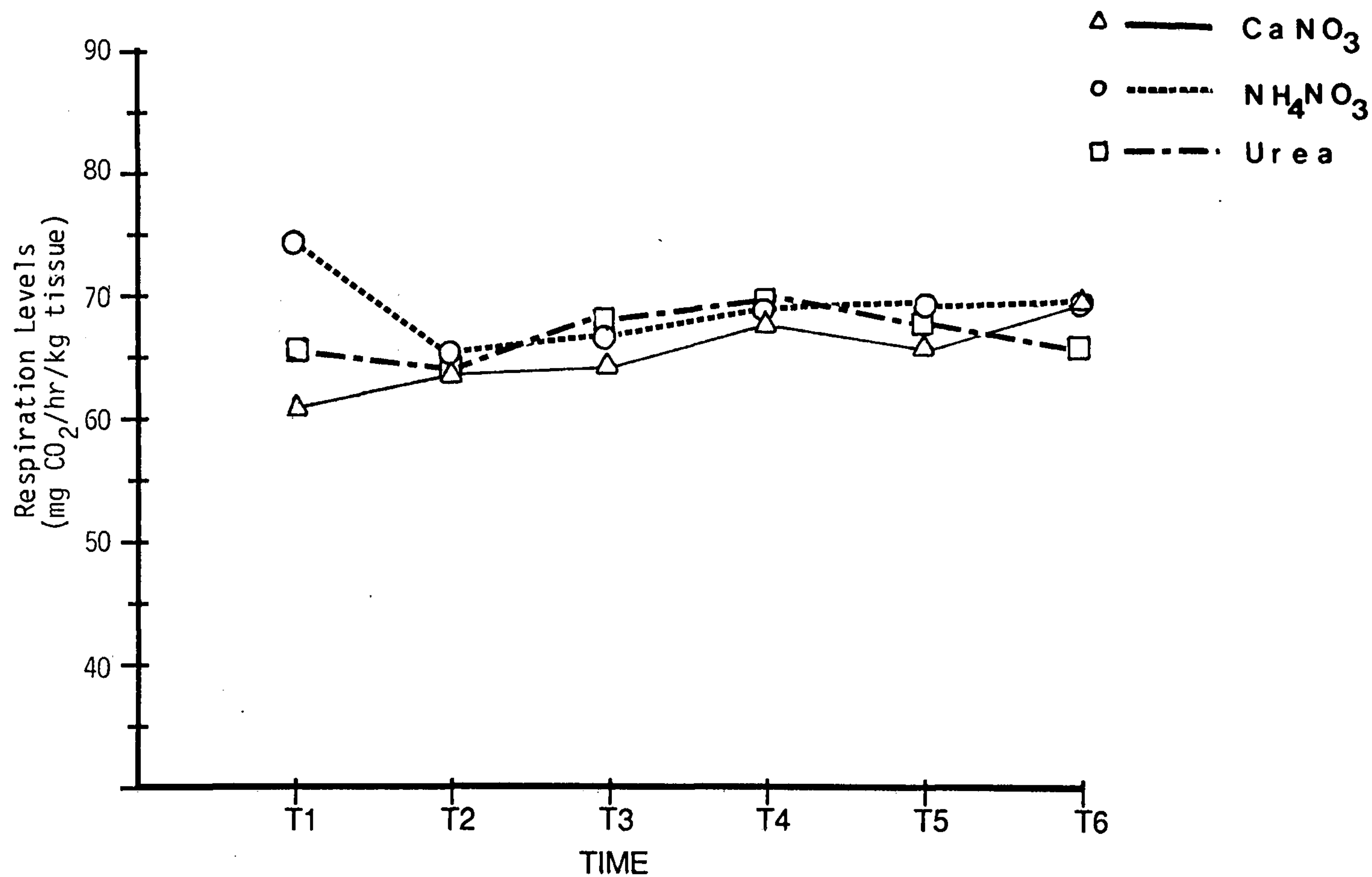

Figure 10. Effects of nitrogen sources and sampling time in storage on respiration ($mg\ CO_2/hr/kg$) levels at 4.4°C. Values represent 3 replications per mean.

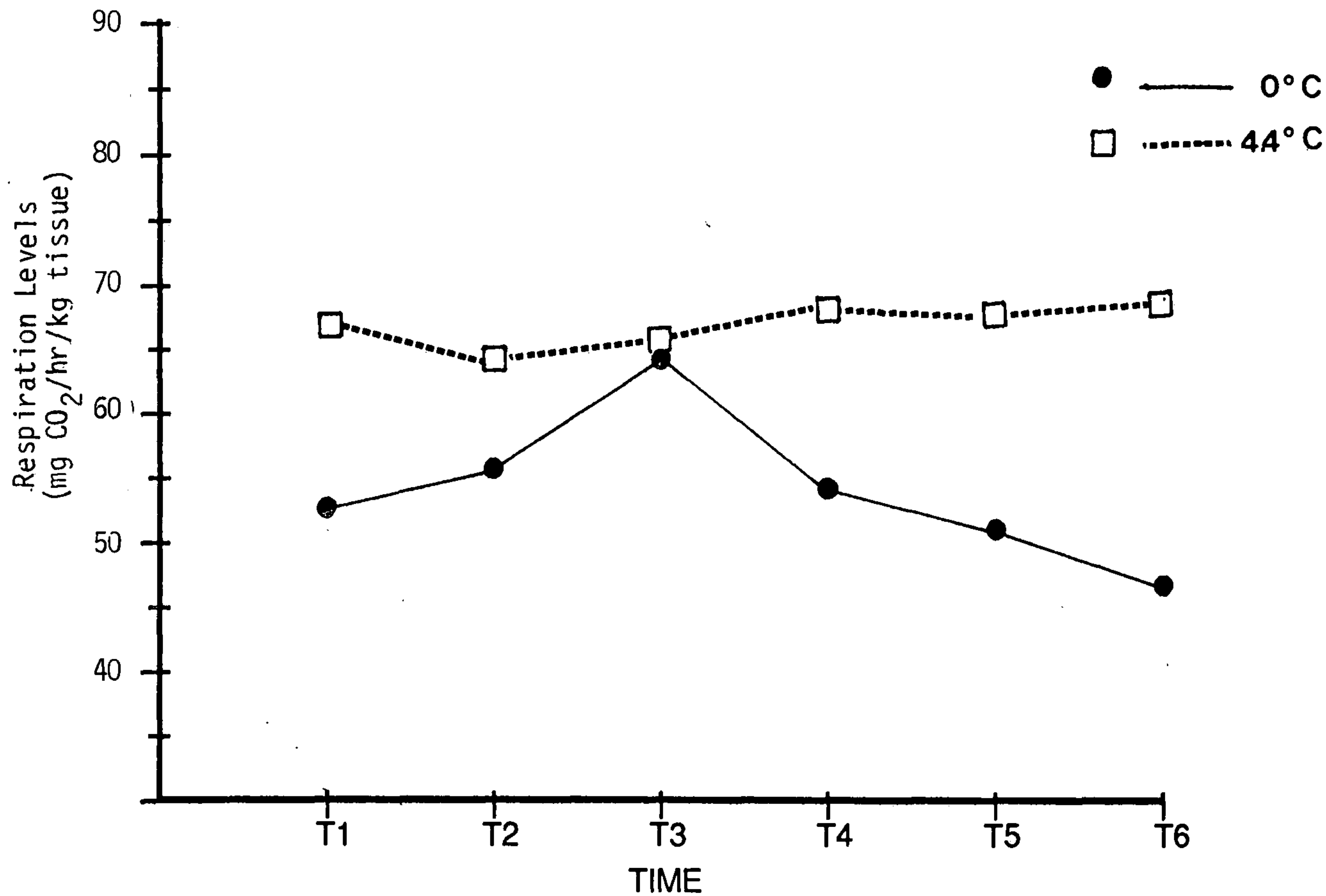

Figure 11. Effect of sampling time in storage on respiration (mg CO_2/hr/kg) levels at 0°C and 4.4°C, with nitrogen sources pooled. Values represent 9 samples per mean.

temperature (Figure 11). Ascorbic acid levels for the 4.4^{o}C broccoli were lower than the broccoli from the 0^{o}C temperature. Metabolic changes are occurring at a more rapid pace in the warmer broccoli thus leading to a decline in factors such as Vitamin C and storage life.

Significance of the nitrogen source and temperature interaction is originating from the difference exhibited in the 0^{o}C room. The respiration values from the broccoli of the $CaNO_3$ and NH_4NO_3 fertilizer sources were much lower than the values of the broccoli from the urea fertilizer source.

Effects of Irrigation and Density on Yield and Ascorbic Acid Content

Yields of 'Gem' broccoli were not significantly affected by the irrigation or density treatments (Tables 2 and 3). Average yield at the higher density, 9.8 MT/ha, was 10% higher than at the lower density, 8.9 MT/ha, though not significant.

The M3 and the M2 treatment yielded an average of 9.7 MT/ha versus the dry or M1 treatment yield of 8.0 MT/ha, an increase of 21% (Table 3). Total water applied was 12.9 cm for the M1 treatment; 17.4 cm for the M2; and 19.1 cm for the M3 treatment (Appendix, Table 1) during the differential treatment periods. Rainfall measurements indicate 0.02 cm fell in August (Appendix Table 2).

Table 2. Influence of two irrigation treatments and two planting densities on yield of broccoli (data shown are in MT/ha).

	MT/ha DENSITY		IRRIGATION MEANS
Irrigation	D1	D2	
M 2	9.2[y]	9.8	9.5
M 3	8.6	9.7	9.2
DENSITY MEANS	8.9	9.8	

[y]No significant effect of irrigation or density treatments.

Table 3. Influence of three irrigation treatments on yield, number of heads, average head weight and ascorbic acid content.

Treatment	TOTAL MT/ha	% Spears	% Stalk	Heads Per ha	Head wt. in g	Ascorbic Acid mg/100 g. fresh wt. Spears	Stalk
M1D2	8.0[y]	57.2	42.8	61,728	95	81.7	65.3
M2D2	9.8	56.4	43.6	70,370	99	83.5	66.5
M3D2	9.7	59.7	40.3	63,786	109	84.3	68.0

[y] No significant effect of irrigation treatments.

An increase in growth rate occurs as the vegetative buds of broccoli undergo a transition to the reproductive stage; thus, this is a time when broccoli is most sensitive to water stress (32,55). Adequate irrigation at time of pre-heading through heading is necessary during the growing season to produce maximum yields of a high market quality (36). More dramatic differences in yield and head size may have occurred if the irrigation treatments had begun seven to ten days earlier.

Morphology of the broccoli plant changed with the increase in plant population. The wider spacing resulted in plants with large, bowl shaped inflorescences while the closer spacings resulted in tall, thin plants with small inflorescences. The number of heads per hectare and the average head weight were significantly affected by density (Tables 4 and 5).

These effects of planting density are in agreement with the findings of Massey (36). Total usable yield per hectare is usually increased by higher density planting (36,42,63). However, in the present study there was only a 10% yield difference between the two densities.

Hollow stem, bractiness and overmature spears were not as evident in the higher density broccoli as in the lower density treatment broccoli. These negative qualities have been associated with large head size (10,22). Broccoli at higher density exhibited more bud uniformity

Table 4. Influence of two irrigation treatments and planting densities on the number of broccoli heads per hectare.

	HEADS PER HECTARE		
	DENSITY		IRRIGATION MEANS
Irrigation	D1	D2	
M 2	22,633	70,370	46,502
M 3	22,839	63,786	43,313
DENSITY MEANS	22,736[y]	67,078[y]	

[y] Significant at 0.05 level.

Table 5. Influence of two irrigation treatments and two planting densities on the average head weight in grams of broccoli.

HEAD WEIGHT IN G.			
	DENSITY		IRRIGATION MEANS
Irrigation	D1	D2	
M 2	299	99	199
M 3	269	109	189
DENSITY MEANS	284[y]	104[y]	

[y]Differences significant at the 0.05 level.

than did the lower density treatments. The positive qualities exhibited by the broccoli of the higher plant population are similar to the qualities of uniform color, bud uniformity and low incidence of hollow stem and axillary bud development discussed by Thompson and Taylor (58,59) in their work on plant population and yield of broccoli.

Ascorbic acid levels of spears and stalks were not affected by the irrigation treatments but density did have a significant effect (Tables 6 and 7). Ascorbic acid levels were higher in spears and stalks of the higher density. One possible explanation could be the effect of light intensity on the plants' ascorbic acid synthesis. Some studies have indicated higher ascorbic acid values for plants exposed to higher light intensities (48). The plants at the higher densities were tall with their heads well exposed to the light while the plants at the lower density were shorter with portions of the head shaded.

Table 6. Influence of two irrigation treatments and two planting densities on the ascorbic acid content of broccoli spears (data shown are in mg/100 g fresh weight.)

ASCORBIC ACID - SPEARS			
	DENSITY		IRRIGATION MEANS
Irrigation	D 1	D2	
	mg/100 g fresh wt.		
M 2	73.7	83.5	78.6
M 3	78.9	84.3	81.6
DENSITY MEANS	76.3[y]	83.9[y]	

[y]Differences significant at 0.05 level.

Table 7. Influence of two irrigation treatments and two planting densities on the ascorbic acid content of broccoli stalks (data shown are in mg/100 g fresh weight).

ASCORBIC ACID - STALKS

Irrigation	DENSITY D 1	D2	IRRIGATION MEANS
	mg/100g	fresh wt	
M 2	57.7	66.5	62.1
M 3	59.0	68.0	63.5
DENSITY MEANS	58.4[y]	67.3[y]	

[y]Differences significant at the 0.05 level.

CONCLUSIONS

Nitrogen source had no effect on broccoli yield, on the ratio of spear tissue to stalk tissue, ascorbic acid content but did have an effect on respiration levels. Broccoli stored for a shorter time period at a temperature of 0°C will have higher ascorbic acid content than broccoli stored at warmer temperatures or stored for long time periods. Respiration values could not be correlated with ascorbic acid values as they increased or decreased through the storage period.

Variations in the values of ascorbic acid and respiration levels can be attributed to either sampling variability (Unpublished data, 1978, Richardson) or the unexplained increases and decreases in levels reported by other researchers in their measurements of ascorbic acid (43,52). This variability could be examined in further studies to ascertain the possibility of regeneration of ascorbic acid while a commodity is in storage.

Irrigation and plant spacing treatments did not affect broccoli yield. Broccoli at the higher plant density exhibited higher bud uniformity, a lower incidence of hollow stem and bractiness, and uniformly smaller heads.

Higher plant densities produced broccoli with a higher ascorbic acid content. Irrigation treatment had no effect on ascorbic acid content which contradicts previous work (24,27,57) in which plants exposed to drier growing periods had higher ascorbic acid content.

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APPENDIX

Appendix Table 1. Irrigation schedule and quantities of water applied July 28 through September 2.

Treatment	No. of Irrigations	Dates of Irrigation	Total Applied in cm. 7/28 - 9/2/80
M 1	4	7/30 , 8/6 8/8 , 8/19	12.9
M 2	6	7/28, 7/30, 8/6, 8/8, 8/14, 8/21	17.4
M 3	15	3 x/week	19.1

4 cm water applied prior to 7/28/80.

Appendix Table 2. Metrological Data - June 1980

Hyslop Field Laboratory

	Air Temperature 107 CM		Precipitation	Evaporation
	Max	Min	Cm.	Cm.
Total			4.4	12.1
Mean	19.9	9.0		

Meteorological Data - July 1980

Hyslop Field Laboratory

	Air Temperature 107 cm.		Precipitation	Evaporation
	Max	Min	Cm.	Cm.
Total			.6	20.7
Mean	27.0	11.4		

Meteorological Data - August 1980

Hyslop Field Laboratory

	Air Temperature 107 cm.		Precipitation	Evaporation
	Max	Min	Cm.	Cm.
Total			.03	18.0
Mean	26.3	8.5		

Meteorological Data - September 1980

Hyslop Field Laboratory

	Air Temperature 107 cm		Precipitation	Evaporation
	Max	Min	Cm.	Cm.
Total			2.4	12.9
Mean	24.7	8.4		