EFFECTS OF NITROGEN AND WITHIN-ROW SPACING ON STALK SHEAR FORCE, STALK DIAMETER AND YIELD OF BROCCOLI

BY

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Bachelor of Science in Education

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Weatherford, Oklahoma

1984

Submitted to the faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirement for
the Degree of
MASTER OF SCIENCE
December, 1988

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PREFACE

The following study was concerned with yield and quality of broccoli. The primary objectives were to study the interaction of nitrogen fertility and within-row spacing on quality aspects of broccoli, including stalk diameter and stem toughness and to determine the nitrogen and spacing system best suited to maximize yield of marketable quality broccoli under Oklahoma conditions. Four nitrogen rates and two spacings were used to compare yield and stalk diameter and stem toughness.

I would like to express my sincere appreciation for the guidance and assistance provided by my major adviser, Dr. Brian A. Kahn, during my Master's program. Sincere thanks is also due to the other members of my advisory committee, Dr. James E. Motes and Dr. Alex B. Filonow for their advisement during the course of my studies.

I would also like to thank Dr. Gerald H. Brusewitz, for his help with the Instron and Dr. Ron McNew and Dr. Mike Smith for their help with the statistics. Thanks is also due Mrs. Debbie Robinson for her help with the computer and Prof. Paul Mitchell for his encouragement and support.

A very special thanks to my wife Sue for her patience and understanding.

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CHAPTER I

INTRODUCTION

Broccoli (Brassica oleracea L.,Italica Group) is grown for its edible stalk and flower buds. Broccoli is increasing in importance going from 3,640 ha in 1939 to over 28,300 ha in 1977 (Ware and McCollum 1980).

The commercial vegetable producer's goal is to obtain a high yield of marketable quality produce. High yield can be obtained by the correct use of cultural practices. These cultural practices include the nitrogen fertilization and plant spacing best suited for the climatic and environmental conditions present.

Research has been done with broccoli to determine the best combination of nitrogen fertilization and plant spacing that will maximize yield. These studies were conducted in a number of places including California (Aldrich et al. 1961; Zink and Akana, 1951; Zink 1968), Canada (Cutcliffe 1971, 1972, 1975a, 1975b), Minnesota (Dufault and Waters 1985), Ohio (Gorski and Armstrong 1985), and Texas (Hipp 1974). However, no research has been done to find the combination of nitrogen fertilization and plant spacing best suited for the specific climatic and environmental conditions of Oklahoma.

In addition to high yield the commercial grower is concerned with producing a product of marketable quality. Research into quality aspects of broccoli has concentrated on hollow stem, Zink 1968;

Cutcliffe 1972; Hipp 1974; Gorski and Armstrong 1985. Other quality aspects of broccoli, particulary stalk toughness have received little or no attention.

The texture of a system is determined by the elements that provide the system with structure and organization. These include the solid components-cell wall and cementing structures and the flow products-suspended solids and dissolved polymeric components. The texture of a commodity is a function of the quality and quantity of these components. The components and their quantities vary depending on the life functions occurring both pre- and post- harvest, and also are influenced by conditions during processing. Texture is a dynamic condition changing according to the physical and chemical reactions occurring among the solid and flow components of the commodity (Hoff 1973).

Chain store buyers have rejected Oklahoma broccoli citing large stalk diameters and unacceptably tough stalks. Growers have attempted to overcome these problems by increasing nitrogen fertilization and decreasing plant spacings. The effect of nitrogen and plant spacing on broccoli stalk diameter and stem toughness has not been studied.

The present study was conducted to accomplish the following objectives:

1. Determine whether nitrogen or within-row spacing affect quality of broccoli.
2. Examine combinations of nitrogen and within-row spacing to begin to determine the best combination for maximizing yield of marketable quality broccoli under Oklahoma conditions.

CHAPTER II

LITERATURE REVIEW

Broccoli Studies

Nitrogen and Spacing in Broccoli

A number of researchers have studied combinations of nitrogen and spacing to attempt to maximize yield for their particular area.

Zink and Akana (1951) used between plant spacings ranging from 4 to 20 inches (10 to 51 cm). They found that as plant spacings decreased, total yield increased. However, head diameter, average weight, stem diameter, and percent of heads and stems equalling or exceeding the freezing specifications [stem not less than 3/4 inch (2 cm) in diameter, head not less than 2 1/4 inches (6 cm) in diameter] decreased.

Aldrich et al. (1961) used between plant spacings ranging from 2 to 18 inches (5 to 46 cm). Maximum yield was obtained at spacings between 8 and 11 inches (20 to 28 cm). Broccoli production dropped dramatically at below optimum spacings. Increases in spacing between plants caused increases in head and butt diameters and also produced an increase in earliness of harvest.

Massey et al. (1962) used spacings of 12 & 18 inches (30 and 46 cm). The 12 inch (30 cm) spacing had the the highest yield.

Zink (1968) used plant spacings of 8, 12, 16, and 20 inches (20, 30, 41, and 51 cm) in combinations with 50, 100, and 200 lbs.of N per acre (56, 112, and 224 kg $N \cdot ha^{-1}$). He found that as plant spacing and nitrogen increased, average stem diameter, average bud diameter, and average weight increased. Increased nitrogen and spacing also resulted in an increased incidence of hollow stem. Percent return decreased as plant spacing decreased but total yield increased.

Palevitch (1970) used within-row spacings of 20, 30 and 40 cm and between row spacings of 50 and 70 cm. The closest within-row spacing produced the highest yield, and plants in a square arrangement (approaching equidistance) produced a higher yield than the same numer of plants in a rectangular arrangement.

Cutcliffe and associates conducted several studies with broccoli in Canada. A 1968 study examined the effect of nitrogen, phosphorus, potassium and manure on yield and maturity. Nitrogen rates ranging from 0 to 336 kg $N \cdot ha^{-1}$ were used. Maximum yield was obtained in a range of 175 to 250 kg $N \cdot ha^{-1}$. Phosphorus and manure applications also increased yield but potassium had no effect.

A 1971 study by Cutcliffe considered the effect of plant population and nitrogen on yield and maturity. He used in-row spacings ranging from 20.3 to 50.8 cm and nitrogen rates of 0, 90, and 180 kg $N \cdot ha^{-1}$. He found that plant spacing had little affect on total marketable yield of single-harvested broccoli. Closer plant spacings produced lower head weight, a lower percentage of marketable heads, and delayed maturity. Increased nitrogen increased total marketable yield, increased head weight and increased the percentage of marketable heads but delayed maturity. A 1972 study by Cutcliffe considered the effect of plant spacing and nitrogen on incidence of hollow stem in broccoli.

He found that as nitrogen and spacing increased incidence of hollow stem increased, but nitrogen had less of an effect than did spacing. A second study (Cutcliffe, 1975b) examined cultivar and spacing effects on incidence of hollow stem. Cutcliffe found a difference in cultivar susceptibility to hollow stem and an increase in hollow stem, as spacing increased.

A 1975 study by Cutcliffe used plant spacings ranging from 20.3 to 50.8 cm and several cultivars of broccoli. He found that closer plant spacings resulted in higher total yields and lower head weights. Cultivars differed in response to spacing, with some cultivars demonstrating delayed maturity as a result of closer spacing.

Hipp (1974) used nitrogen rates of 0, 56, 112, 168, and 224 kg $N \cdot ha^{-1}$. As nitrogen increased from 0 to 168 kg $N \cdot ha^{-1}$, yield also increased. Less of an effect was noted as nitrogen increased from 168 to 224 kg $N \cdot ha^{-1}$. Increased nitrogen resulted in earlier maturity. He found that percent hollow stem increased as nitrogen rate increased, but the increase in yield was greater than the loss due to hollow stem.

Greenwood et al. (1980) reported broccoli yields ranging from 7 to 22 $t \cdot ha^{-1}$ in two nitrogen experiments, with an average of 15 $t \cdot ha^{-1}$. The optimum rate of nitrogen was reported to be 248 $kg \cdot ha^{-1}$. Withholding nitrogen or applying excessive nitrogen resulted in a 4-to 6-fold increase in the percentage of immature terminal shoots over that obtained when the optimum level of nitrogen was applied.

Chung (1982) studied the effect of plant density on maturity and yield of broccole for once-over harvest. He used plant densities ranging from 2.1 to 98.0 plants m^{-2}. Increased plant density resulted in reduced head and butt diameter. Highest yield was obtained at plant densities of 20 plants m^{-2}. A similar study conducted by Chung (1985) examined the effects of sowing time and plant density. He found that the optimum plant density for maximizing percent return on broccoli varied according to the season of production. Increased plant density (from 2.8 to 49.0 plants $\cdot$ m^{-2}) reduced average head weights, head diameters, and butt diameters.

Letey et al. (1983) reported that broccoli growth and average head weight increased as nitrogen rate increased from 90 to 270 kg $N \cdot ha^{-1}$.

Salter et al. (1984) obtained maximum broccoli yields from square planting arrangements compared to those with greater rectangularity. Yield was insensitive to densities above 20 plants $\cdot$ m^{-2}, but mean head size decreased with increasing density. There was no obvious relantionship between uniformity of maturity and density.

Dufault and Waters (1985) also studied nitrogen and betweėn plant spacing combinations. They used plant spacings of 15, 30, and 45 cm and nitrogen rates of 56, 112, 168, and 224 kg $N \cdot ha^{-1}$. They found that as nitrogen rates increased, marketable head weight and total marketable yield increased linearly and cull production decreased linearly. As plant spacings decreased total marketable yield increased but marketable head weight decreased. Spacing had less of an effect on cull production than did nitrogen. Neither nitrogen nor spacing had an effect on early maturity.

Gorski and Armstrong (1985) used nitrogen rates of 0, 112, 168, and 224 kg $N \cdot ha^{-1}$, and plants pacings of 20, 30, and 40 cm. As nitrogen increased from 0 to 168 kg $N \cdot ha^{-1}$, total yield and average head weight increased, but less of an effect was noted as nitrogen was increased from 168 to 224 kg $N \cdot ha^{-1}$. As plant spacing decreased, total yield increased but average head weight decreased. Increased nitrogen and spacing resulted in an increased incidence of hollow stem. Earlier yields were obtained with the higher nitrogen rates (168 or 224 kg $N \cdot ha^{-1}$) than with the lower rates (0 or 112 kg $N \cdot ha^{-1}$). Fall broccoli produced earlier yields at the closer plant spacings than at the wider plant spacings. Earliness of harvest for spring broccoli was not affected by spacing.

Beverly et al. (1986) reported that with sprinkler irrigation approximately twice a week, relatively low N rates (140 $kg \cdot ha^{-1}$) provided the lowest nitrogen and water cost for a 10,000 $kg \cdot ha^{-1}$ yield of broccoli. In this study, broccoli receiving nitrogen treatments (0 to 331 $kg \cdot ha^{-1}$) reached horticultural maturity at about the same time, but an increased growth rate resulted in higher yields with the higher nitrogen treatments.

Instron Studies

Use of the Universal Instron Testing Machine to Measure Texture

The Universal Instron Testing Machine has been used by several researchers to obtain an objective measure of texture of a number of horticultural crops.

Lipton and Harris (1974) used the Instron to measure tenderness of cooked broccoli. Lee and Bourne (1980) used the Instron to perform puncture tests on grapes in order to determine firmness during berry maturation. Davis et al. (1981) used the Instron in evaluating firmness of stored and packed cucumbers. Thomposon et al. (1982) also studied firmness in cucumber and used the Instron to measure maximum penetration force through cucumber slices. Pitt (1984) used the Instron to study failure mechanics in potatoes.

CHAPTER III

MATERIALS AND METHODS

The experiments were conducted at the Vegetable Research Station, Bixby, Oklahoma on a Severn very fine sandy loam [coarse-silty, mixed (calcareous) thermic Typic Udifluvents]. A preplant-incorporated application of trifluralin at 560 $g \cdot ha^{-1}$ was made prior to each experiment to control weeds. Preplant-incorporated diazinon at 2.2 $kg \cdot ha^{-1}$ was used for soil insect control in the two spring experiments. Standard commercial foliar insecticides were applied as required.

A split-plot design was used. Nitrogen rates were assigned to main plots and arranged as a Latin square, while within-row spacings were assigned to sub-plots. There were four replications.

Single degree of freedom contrasts were used to determine linear, quadratic, and cubic responses to nitrogen rates. Data was analyzed using general linear modules procedures of SAS for microcomputers. Double row plots 2.5 m long were used, with 30 cm between the two rows within each plot and 90 cm between centers of the plots. Within-row spacings were 15 or 30 cm between plants. Nitrogen rates were planned to be 56, 112, 168, and 224 $kg \cdot ha^{-1}$in Fall 1986 and 112, 168, 224, and 280 $kg \cdot ha^{-1}$ thereafter. These rates were to be achieved by supplementing initial soil N with three equally divided sidedressings using urea: one at planting, a second 2 1/2 weeks after planting, and a third 5 weeks after planting. The actual N rates used and the dates of

TABLE I

DATES OF NITROGEN FERTILIZATION AND RATES OF NITROGEN APPLIED FOR FOUR EXPERIMENTS WITH BROCCOLI

N application dates	N applied ($kg \cdot ha^{-1}$)
20 Aug. 1986 (At planting)	18, 36, 56, 74
10 Sept. 1986 (Sidedress)	19, 38, 56, 75
Treatment totals, Fall 1986	37, 74, 112, 149
13 Feb. 1987 (Preplant)	58 (entire trial area)
20 Mar. 1987 (At planting)	18, 36, 54, 74
7 Apr. 1987 (Sidedress)	18, 37, 56, 74
24 Apr. 1987 (Sidedress)	18, 37, 56, 74
Treatment totals, Spring 1987	112, 168, 224, 280
Residual N (soil test)[z]	39 (entire trial area)
6 Aug. 1987 (Preplant)	58 (entire trial area)
18 Aug. 1987 (At planting)	0, 23, 41, 61
4 Sep. 1987 (Sidedress)	0, 24, 43, 61
Treatment totals, Fall 1987	97, 144, 181, 219
24 Feb. 1988 (Preplant)	60 (entire trial area)
23 Mar. 1988 (At planting)	18, 36, 54, 74
11 Apr. 1988 (Sidedress)	17, 36, 55, 73
26 Apr. 1988 (Sidedress)	17, 36, 55, 73
Treatment totals, Spring 1988	112, 168, 224, 280

[z] Residual soil N was negligible in the other three experiments.

N fertilization are shown in Table I.

Plug-type transplants of 'Premium Crop' broccoli were obtained from a commercial source (Speedling, Inc., Sun City, Fla.) for each experiment. The rooting medium volume was about 18 cm^3 per plug. Each transplant received about 200 ml of starter solution at planting. The starter solution for the 30 cm spacing provided 719 N - 316 P - 597 K ($mg \cdot liter^{-1}$), respectively, plus 253 $mg \cdot liter^{-1}$ diazinon. Half-strength starter solution was used for the 15 cm spacing to ensure equivalent rates per unit area. Planting dates are shown in Table 1.

Petiole samples were taken prior to heading from three plants per plot to measure nitrogen content. The first visibly expanded leaf at the apex was noted on each plant; then, proceeding basipetally, the sixth leaf was identified and severed from the plant. Leaf blades were stripped from the petioles. Petioles were dried at 70 C, ground to pass a 20 mesh screen, and analyzed for percent N using the Kjeldahl technique.

At harvest, plants were cut near the base and leaves were removed. Heads were placed against a vertical surface and stalks were trimmed at 20.5 cm from the top of the dome. Heads then were weighed, measured for stalk diameter at the newly-cut end ("butt"), and classified as "marketable" or "cull". Reasons for culling were yellow or senescent beads; uneven domes (due to unequal flower stalk lengths or extreme difference in bud sizes); or a fresh weight of less than 80 g. Hollow stem was negligible in all four experiments. Marketable heads were placed in plastic bags and held at 5 C.

Maximum stalk shear force was measured within 24 hr. of harvest at the OSU Agricultural Engineering Laboratory in Stillwater. Heads again were placed against a vertical surface and stalks were marked at 17 and 15 cm from the top of the dome. Stalks then were sheared, first at 17 cm and then at 15 cm, using an Instron Universal Testing Machine (Instron Corp., Canton, Mass.) equipped with a 500 kg reversible load cell-(Assembly A217-17) and a modified shear plate (Figure 1). The crosshead speed was 2.0 cm per minute, with a chart speed of 2.5 cm per minute; full scale on the chart was 50 kg.

Fall 1986

A preplant soil test indicated 5.6N (NO_3^-) - 147P - 292K ($kg \cdot ha^{-1}$), respectively. No preplant fertiliztion was used. Plots were sprinkler-irrigated on 20, 21, 22, and 25 Aug. In late September, a century flood occurred. This prevented application of the sidedressing scheduled for 5 weeks after planting, caused the loss of one replication, and delayed plant sampling for N content until 3 Nov. (during harvest). However, the experiment was continued in order to determine whether the stresses imposed would result in production of tough stalks. Seven harvests were made between 20 Oct. and 10 Nov. as central heads matured. Side shoots were not harvested in this or later expirements.

Spring 1987

A preplant soil test indicated 4.5N (NO_3^-) - 180P - 296 K ($kg \cdot ha^{-1}$), respectively. Soil was prepared with a broadcast, preplant-incorporated application of 58N - 26P - 48K ($kg \cdot ha^{-1}$), respectively. Plots were sprinkler-irrigated on 13, 18, and 21 May. Plants were sampled for N content on 7 May. Six harvests were made between 19 May and 4 June as central heads matured.

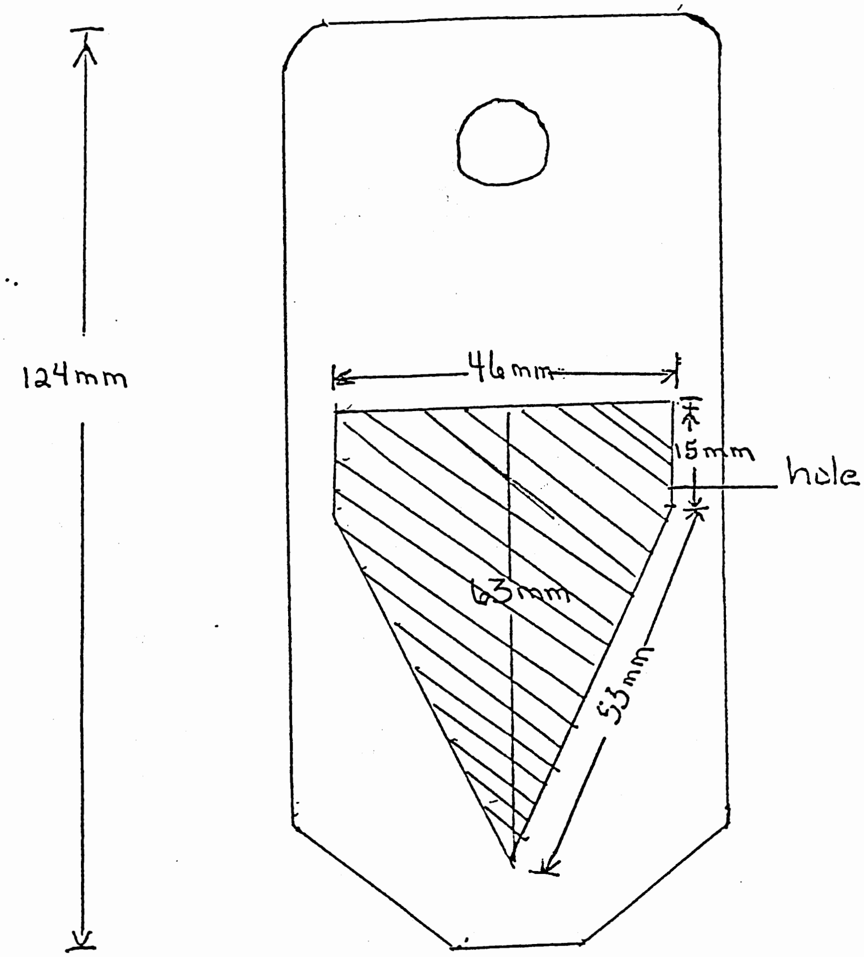

Figure 1. Instron Shear Plate Used to Determine Maximum Stalk Shear Force of Broccoli. Shear plate is shown actual size.

Fall 1987

A preplant soil test indicated 39.2N (NO_3^-) - 172P - 371K ($kg \cdot ha^{-1}$), respectively. Soil test results were delayed, so the soil was prepared with a broadcast, preplant-incorporated application of 58N -26P - 48K ($kg \cdot ha^{-1}$), respectively. When the unexpectedly high residual soil N was discovered, sidedressing rates were adjusted accordingly. However, plant growth was so vigorous that the canopy closed before the sidedressing scheduled for 5 weeks after planting could be applied. Plots were sprinkler-irrigated on 19 and 24 Aug. and on 9 Oct. Plants were sampled for N content on 2 Oct. Six harvests were made between 15 Oct. and 2 Nov. as central heads matured.

Spring 1988

A preplant soil test indicated 4.5N (NO_3^-) - 112P - 265K ($kg \cdot ha^{-1}$), respectively. Soil was prepared with a broadcast, preplant-incorporated application of 60N - 27P - 50K ($kg \cdot ha^{-1}$), respectively. Plants were sampled for N content on 12 May. Four harvests were made between 23 May and 3 June as central heads matured.

CHAPTER IV

RESULTS AND DISCUSSION

Nitrogen and Spacing Effects

Maximum Stalk Shear Force

One of the stated objectives of this study was to determine whether nitrogen or within-row spacing affect quality of broccoli, particularly stalk toughness, which was objectively measured by use of the Universal Instron Testing Machine. The maximum stalk shear force was measured at 15 and 17 cm, and the average was used for statistical analysis.

Factors such as insufficient water and low nitrogen stress the plant and check growth. We would expect these stresses to result in more fiborous and tough stalks. In contrast, adequate water and ample nitrogen should result in more succulent and tender plant tissue.

Within-row spacing had no significant effect on maximum shear force in any of the experiments. (Table II)

The larger maximum shear force values of Fall 86 may be attributed to flooding that occurred during that experiment (Table II). Excess water would have stressed the plants and would have accelerated leaching of nitrogen.

There was no significant effect of nitrogen in Fall 86, Fall 87 or Spring 87. However, in Spring 87 there was a trend towards lower

TABLE II

THE EFFECT OF NITROGEN AND SPACING ON MAXIMUM STALK SHEAR FORCE

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Max. stalk shear force (kg) F86	F87	S87	S88
15	37	97	112	112	22	16	17	18
15	74	144	168	168	23	15	16	16
15	112	181	224	224	22	15	15	16
15	149	219	280	280	22	16	14	17
30	37	97	112	112	23	16	16	19
30	74	144	168	168	23	16	16	17
30	112	181	224	224	23	16	15	17
30	149	219	280	280	20	16	16	16
Nitrogen					NS	NS	NS	N-L**
Spacing					NS	NS	NS	NS
N x Spacing					NS	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

maximum shear at the highest nitrogen rates, although it was not significant. In Spring 88 there was a response to nitrogen, resulting primarily from a higher maximum shear at the lowest nitrogen rate (Table II).

As previously discussed, texture is a dynamic condition resulting from the combination of physical and chemical reactions occurring in the plant. Fall growing conditions for broccoli in Oklahoma generally are more favorable than spring growing conditions. In spring, hot days near the end of the growing season can stress the broccoli plant. The combination of spring growing conditions and low nitrogen may have resulted in the nitrogen effect found in Spring 88. This trend was also seen in Spring 87 but it was not significant. Lower nitrogen rates were used in fall experiments but no nitrogen effect was noted possibly due to the better environmental conditions present.

Average Marketable Head Stalk Diameter

While the ideal stalk diameter has not been set, in general consumers prefer to buy a 680 to 900 g bunch made up of 4 to 6 stalks rather than one containing 2 or 3 large stalks or 9 to 12 of a smaller size (Zink and Akana 1951). Stalk diameter was another specific quality aspect of broccoli studied in this experiment.

Spacing effects were significant in all experiments with a larger stalk being produced at the 30 cm spacing than at the 15 cm spacing (Table III). These findings agree with Zink and Akana (1951), Aldrich et al. (1961), Zink (1968) and Chung (1982), who found that stalk diameter decreased as spacing decreased.

TABLE III

THE EFFECT OF NITROGEN AND SPACING ON AVERAGE MARKETABLE HEAD STALK DIAMETER

Spacing	N rates ($kg \cdot ha^{-1}$)				Avg. marketable head stalk diam. (mm)			
(cm)	F86	F87	S87	S88	F86	F87	S87	S88
15	37	97	112	112	29	29	28	29
15	74	144	168	168	28	29	28	28
15	112	181	224	224	29	29	29	31
15	149	219	280	280	30	28	28	29
30	37	97	112	112	29	32	32	31
30	74	144	168	168	31	31	31	33
30	112	181	224	224	32	33	32	32
30	149	219	280	280	33	33	32	33
Nitrogen					N-L*	NS	NS	NS
Spacing					S*	S*	S*	S*
N x Spacing					NS	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

Nitrogen had no effect on stalk diameter except in Fall 86, when extremely low nitrogen was used (Table III). It appears that once nitrogen is sufficient there is no effect of nitrogen on average head stalk diameter.

Total Cull Head Number and Weight

Cull production is unfavorable to the grower and is expensive in terms of time, money and labor. For these reasons growers seek to keep cull production to a miniumum.

Cull number and cull weight measured here are based on culls during harvest and do not include culls left in the field after harvest was completed.

Spacing had an effect on cull number with the 15 cm spacing producing a greater number of culls than the 30 cm spacing (Table IV).

Spring 87 showed an increase in cull number (Table IV) and cull weight (Table V) compared to fall harvests while in Spring 88 cull number (Table IV) and cull weight (Table V) were comparable to fall harvests. However, Spring 88 reflected only four harvests compared to six and seven harvests in the three other experiments. Hot, dry conditions in Spring 88 led to an early termination of harvest. Overall spring broccoli produced greater cull number and cull weight than fall broccoli.

In the spring nitrogen had no significant effect on cull number (Table IV) or cull weight (Table V). It appears that under the less favorable growing conditions of spring in Oklahoma, increased nitrogen would have little benefit in reducing cull production. This is in contrast to Dufault and Waters (1985) who had a linear decrease in cull

TABLE IV

THE EFFECT OF NITROGEN AND SPACING ON TOTAL CULL HEAD NUMBER

Spacing	N rates ($kg \cdot ha^{-1}$)				Total cull heads ($Thousands \cdot ha^{-1}$)			
(cm)	F86	F87	S87	S88	F86	F87	S87	S88
15	37	97	112	112	68	22	66	12
15	74	144	168	168	49	20	60	22
15	112	181	224	224	23	15	62	17
15	149	219	280	280	10	8	65	14
30	37	97	112	112	23	5	32	11
30	74	144	168	168	10	6	23	8
30	112	181	224	224	12	2	26	9
30	149	219	280	280	2	5	26	3
Nitrogen					--	N-L*	NS	NS
Spacing					--	S**	S**	S**
N x Spacing					N-L x S**	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

TABLE V

THE EFFECT OF NITROGEN AND SPACING ON TOTAL CULL HEAD WEIGHT

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Total cull heads ($t \cdot ha^{-1}$) F86	F87	S87	S88
15	37	97	112	112	3.6	1.9	5.5	1.0
15	74	144	168	168	3.2	1.6	5.4	2.2
15	112	181	224	224	1.5	1.2	5.7	1.7
15	149	219	280	280	0.7	0.6	6.1	1.2
30	37	97	112	112	1.6	0.3	4.5	1.3
30	74	144	168	168	0.6	1.2	4.0	1.0
30	112	181	224	224	1.4	0.1	3.6	1.3
30	149	219	280	280	0.2	0.8	4.6	0.5
Nitrogen					--	NS	NS	NS
Spacing					--	S*	NS	NS
N x Spacing					N-C x S*	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

head production in response to nitrogen during a spring planting in Minnesota.

In the fall experiments increased nitrogen resulted in decreased cull number and weight, especially at the 15 cm spacing (Tables IV and V). In Fall 86 at 15 cm as nitrogen increased cull production decreased (Tables IV and V). At the 30 cm spacing cull production decreased sharply going from the lowest nitrogen rate 37 $kg \cdot ha^{-1}$ to 74 $kg \cdot ha^{-1}$ but less of an effect was noted with further nitrogen increases (Tables IV and V). This suggests that under fall conditions, increased levels of nitrogen may reduce cull production when broccoli is grown at 15 cm spacings, but will have less of an effect when broccoli is grown at 30 cm spacings.

Total Marketable Number and Weight

The grower is concerned with obtaining the maximum total marketable yield which is economically feasible to produce.

With spring broccoli there was no significant effect of nitrogen on total marketable head number (Table VI) or total marketable weight (Table VII). This is in contrast to a number of researchers who found that as nitrogen increased yield increased (Cutcliffe 1971), (Dufault and Waters 1985), (Gorski and Armstrong 1985). However, their studies were conducted in areas with vastly different spring conditions than those found in Oklahoma.

In Spring 87 spacing had an effect on total marketable head number, with the 15 cm spacing producing more heads than the 30 cm spacing (Table VI). Total marketable head weight was not significantly higher at the 15 cm spacing than at the 30 cm spacing (Table VII), due

TABLE VI

THE EFFECT OF NITROGEN AND SPACING ON TOTAL MARKETABLE HEAD NUMBER

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Total marketable heads ($Thousands \cdot ha^{-1}$) F86	F87	S87	S88
15	37	97	112	112	18	90	31	56
15	74	144	168	168	31	91	57	46
15	112	181	224	224	58	106	65	56
15	149	219	280	280	62	103	59	56
30	37	97	112	112	37	63	34	43
30	74	144	168	168	49	66	34	43
30	112	181	224	224	43	62	43	49
30	149	219	280	280	41	62	37	56
Nitrogen					--	--	NS	NS
Spacing					--	--	S*	NS
N x Spacing					N-L x S**	N-L x S**	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

TABLE VII

THE EFFECT OF NITROGEN AND SPACING ON TOAL MARKETABLE HEAD WEIGHT

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Total marketable heads ($t \cdot ha^{-1}$) F86	F87	S87	S88
15	37	97	112	112	2.0	12.3	3.6	7.0
15	74	144	168	168	3.4	13.1	7.0	5.5
15	112	181	224	224	6.9	15.6	8.7	6.8
15	149	219	280	280	8.0	14.6	7.8	7.4
30	37	97	112	112	3.9	11.2	5.6	7.0
30	74	144	168	168	6.6	12.0	6.1	9.7
30	112	181	224	224	6.8	12.9	7.6	8.6
30	149	219	280	280	7.2	12.4	6.9	9.9
Nitrogen					--	NS	NS	NS
Spacing					--	S**	NS	S**
N x Spacing					N-C x S*	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

to the larger head weight produced at the 30 cm spacing. In Spring 88 spacing had no effect on total marketable head number but total marketable head weight was greater at the 30 cm spacing than at the 15 cm spacing (Tables VI and VII). Again this was due to the larger head weight produced at the 30 cm spacing. This is in contrast to other researchers who found that total yield increased as spacing decreased. (Cutcliffe 1975), (Dufault and Waters 1985), (Gorski and Armstrong 1985). With spring broccoli in Oklahoma it appears that the 30 cm spacing would be best and added nitrogen would have no effect.

With fall broccoli nitrogen had an effect especially at the 15 cm spacing (Tables VI and VII). In Fall 86 at the 15 cm as nitrogen increased total marketable head number (Table VI) and weight (Table VII) increased. This is in agreement with Hipp 1973, and Gorski and Armstrong 1985 who had respones to nitrogen increases with fall broccoli. At the 30 cm spacing as nitrogen increased from the lowest nitrogen rate (37 $kg \cdot ha^{-1}$) to 74 $kg \cdot ha^{-1}$ total marketable head number (Table VI) and weight (Table VII) increased, but subsquent increases in nitrogen rates had little effect. This would indicate that nitrogen was deficient at the 37 $kg \cdot ha^{-1}$ rate. Once nitrogen becomes sufficient little benefit is gained by increasing nitrogen rates at the 30 cm spacing. In Fall 87 at the 15 cm spacing, total marketable head number increased as nitrogen increased (Table VI). Again this would be in agreement with researchers who found a nitrogen response (Hipp 1973), (Gorski and Armstrong 1985). At the 30 cm spacing nitrogen increase had little effect on total marketable head number (Table VI). Total marketable head weight was not significantly affected by nitrogen rate (Table VII). There was a spacing effect in Fall 87 with higher total marketable head number and weight at the 15 cm spacing than the 30 cm spacing (Tables VI and VII). Several other researchers found an increase in yield with a decrease in spacing (Zink and Akana 1951), (Massey et al. 1962), (Cutcliffe 1975), (Dufault and Waters 1985), (Gorski and Armstrong 1985).

For fall broccoli it appears that higher total marketable head number and weight may be obtained at the 15 cm than the 30 cm spacing provided that nitrogen is sufficent.

Average Marketable Head Weight

For this study head weights below 80 grams were considered too small and culled. The upper weight limits were not specified as heads were harvested when marketable size was reached. Generally the growers would prefer the larger marketable head weight.

In both spring and fall experiments spacing had an effect on average marketable head weight, with the larger heads being produced at the 30 cm spacing (Table VIII). This confirmed studies by a number of other researchers (Zink and Akana 1951), (Aldrich et al. 1961), (Zink 1968) (Cutcliffe 1971 and 1975), (Gorski and Armstrong 1985). In Spring 87 there was a trend towards increased head weight as nitrogen increased but it was not significant. In Spring 88 there was significance; as nitrogen increased average head weight increased. These results also confirmed those of Cutcliffe 1971, Dufault and Waters 1985, and Gorski and Armstrong 1985.

In Fall 86 as nitrogen increased average marketable head weight increased. Similar findings were obtained by Gorski and Armstrong 1985. In Fall 87 as nitrogen increased from 97 $kg \cdot ha^{-1}$ to 181 $kg \cdot ha^{-1}$

TABLE VIII

THE EFFECT OF NITROGEN & SPACING ON AVERAGE MARKETABLE HEAD WEIGHT

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Avg. marketable head wt. (g) F86	F87	S87	S88
15	37	97	112	112	103	137	115	128
15	74	144	168	168	104	143	123	119
15	112	181	224	224	121	146	136	119
15	149	219	280	280	139	142	130	133
30	37	97	112	112	103	178	171	162
30	74	144	168	168	137	182	171	175
30	112	181	224	224	159	208	176	176
30	149	219	280	280	177	202	184	177
Nitrogen					N-L**	--	NS	N-L**
Spacing					S*	--	S**	S**
N x Spacing					NS	N-L x S*	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

average marketable head weight increased. As nitrogen increased from 181 $kg\cdot ha^{-1}$ to 219 $kg\cdot ha^{-1}$ no increase in average marketable head weight was noted (Table VIII). It appears for fall broccoli, if nitrogen is deficient, as nitrogen is increased average marketable head weight is increased. Once nitrogen becomes sufficient, additional nitrogen increases will not be beneficial in increasing average marketable head weight.

Petiole Nitrogen Content

This analysis was done by use of the Kjeldahl to determine if the nitrogen being added to the soil was being taken up by the plant.

The nitrogen range for the fall experiments was from 37 $kg\cdot ha^{-1}$ to 219 $kg\cdot ha^{-1}$ (Table IX). In these experiments as nitrogen rates increased, nitrogen uptake or petiole nitrogen content increased. There was no effect of spacing in either fall experiment.

In the spring experiments the nitrogen range was from 112 $kg\cdot ha^{-1}$ to 280 $kg\cdot ha^{-1}$ (Table IX). As nitrogen rates increased from 112 $kg\cdot ha^{-1}$ to 224 $kg\cdot ha^{-1}$ petiole nitrogen content increased. As nitrogen increased from 224 $kg\cdot ha^{-1}$ to 280 $kg\cdot ha^{-1}$ no increase in petiole nitrogen content was noted. It appears that petiole nitrogen content became saturated somewhere around the 224 $kg\cdot ha^{-1}$ nitrogen rate and that further nitrogen rate increases were not getting into the plant.

There was a spacing effect in both spring experiments, with a higher petiole nitrogen content at the 30 cm spacing than at the 15 cm. spacing. This may be due to more competition for the nitrogen at the 15 cm spacing.

TABLE IX

THE EFFECT OF NITROGEN AND SPACING ON PETIOLE NITROGEN CONTENT

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Petiole nitrogen content (%) F86	F87	S87	S88
15	37	97	112	112	.5	2.6	1.9	1.6
15	74	144	168	168	.6	3.2	2.6	2.2
15	112	181	224	224	.8	3.1	2.6	2.6
15	149	219	280	280	.8	3.3	2.6	2.7
30	37	97	112	112	.6	2.2	2.6	2.0
30	74	144	168	168	.6	3.3	2.8	2.5
30	112	181	224	224	.9	3.5	3.0	3.0
30	149	219	280	280	.9	3,7	3.0	2.7
Nitrogen					N-L**	N-L*	N-Q*	N-Q*
Spacing					NS	NS	S**	S*
N x Spacing					NS	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

Overall as nitrogen rate increases the amount of nitrogen taken up by the plant increases, until saturation is reached. Further nitrogen increases are not utilized.

Days to First Harvest

The grower desires and benefits from an early harvest. An earlier harvest can eliminate losses due to frost in fall or excessive heat in the spring. In addition the early harvest often commands the better price.

In all four experiments an earlier harvest was obtained at the 30 cm spacing than at the 15 cm spacing (Table X). This agrees with Aldrich et al. 1961 and Cutcliffe 1975 who found an earlier harvest as spacing increased.

Nitrogen had little or no effect on earliness of harvest, except an inconsistent effect in Spring 87 (Table X). This agrees with Dufault and Waters 1985 who found no effect of nitrogen, but disagrees with Hipp 1973 who found that increased nitrogen increased earliness, and with Cutcliffe 1975 who found that increased nitrogen delayed maturity.

It appears that the grower can obtain an earlier harvest by use of the 30 cm spacing.

Uniformity of Harvest

The grower can save time, money and labor by conducting as few picks as possible. The more uniform the harvest the more beneficial it is for the grower.

TABLE X

THE EFFECT OF NITROGEN AND SPACING ON DAYS TO FIRST HARVEST

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Days to first harvest F86	F87	S87	S88
15	37	97	112	112	76	69	71	67
15	74	144	168	168	74	68	71	68
15	112	181	224	224	73	68	70	69
15	149	219	280	280	73	69	69	67
30	37	97	112	112	73	66	68	67
30	74	144	168	168	72	66	66	66
30	112	181	224	224	71	67	67	66
30	149	219	280	280	72	67	65	66
Nitrogen					NS	NS	--	NS
Spacing					S*	S*	--	S**
N x Spacing					NS	NS	N-C x S*	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

There was no effect of nitrogen on uniformity of harvest in any of the experiments (Table XI).

In Fall 87 there was a spacing effect with a more uniform harvest at the 30 cm spacing than at the 15 cm spacing (Table XI).

It appears that if growing conditions are ideal, a more uniform harvest may be obtained at the the 30 cm spacing. Fall 86 experienced less than ideal growing conditions due to flooding, and spring growing conditions are always less satisfactory in Oklahoma due to the onset of excessive heat near the end of the harvest period. In less than ideal conditions nitrogen and spacing appear to have no effect on uniformity of harvest. Salter et al. 1984 and Cutcliffe 1972 found no effect of spacing on uniformity of harvest.

Percent Return

Percent return is figured by dividing the number of marketable heads by the total number of potential data plants.

The data area contained 12 or 24 plants at the 30 or 15 cm spacing respectively immediately after transplanting. These initial stands (12 or 24 plants) were used as the figures for potential data plants.

The grower desires a high percent return as plants lost to culls are expensive, costing money in transplants, labor and loss productivity.

Spacing had an effect on percent return in all four experiments with a higher percent return at the 30 cm spacing than at the 15 cm spacing (Table XII). This agrees with Zink and Akana 1951, Zink 1968 and Cutcliffe 1971 who found that percent return was higher as within-row spacing increased.

TABLE XI

THE EFFECT OF NITROGEN AND SPACING ON UNIFORMITY OF HARVEST

Spacing (cm)	N rates ($kg \cdot ha^{-1}$) F86	F87	S87	S88	Heads harvested after 2 picks (%) F86	F87	S87	S88
15	37	97	112	112	83	26	73	91
15	74	144	168	168	66	36	62	87
15	112	181	224	224	56	33	70	71
15	149	219	280	280	36	45	66	81
30	37	97	112	112	77	67	81	61
30	74	144	168	168	56	44	74	92
30	112	181	224	224	65	59	62	68
30	149	219	280	280	56	50	73	72
Nitrogen					NS	NS	NS	NS
Spacing					NS	S**	NS	NS
N x Spacing					NS	NS	NS	NS

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

TABLE XII

THE EFFECT OF NITROGEN AND SPACING ON PERCENT RETURN

Spacing	N rates ($kg \cdot ha^{-1}$)				Return on transplants set in field[z] (%)			
(cm)	F86	F87	S87	S88	F86	F87	S87	S88
15	37	97	112	112	13	60	22	38
15	74	144	168	168	21	61	39	31
15	112	181	224	224	39	72	44	38
15	149	219	280	280	42	70	40	38
30	37	97	112	112	50	85	44	58
30	74	144	168	168	64	90	48	75
30	112	181	224	224	58	83	58	67
30	149	219	280	280	56	83	52	75
Nitrogen					--	NS	NS	NS
Spacing					--	S**	S**	S**
N x Spacing					N-L x S*	NS	NS	NS

[z]Calculated as no. marketable heads divided by total no. potential data plants

NS,*,** Non significant (NS) or significant at 5% (*) or 1% (**) levels

N-L, N-Q, N-C = Nitrogen linear, nitrogen quadratic, nitrogen cubic

In Fall 86, at the 15 cm spacing, as nitrogen increased percent return increased (Table XII). This agrees with Cutcliffe 1971 who found higher percent return with increased nitrogen. At the 30 cm spacing as nitrogen increased from 37 $kg \cdot ha^{-1}$ to 74 $kg \cdot ha^{-1}$ percent return increased. As nitrogen increased beyond 74 $kg \cdot ha^{-1}$ no effect of nitrogen on percent return was noted (Table XII). There was no effect of nitrogen in any of the other experiments, all of which had higher nitrogen rates.

It appears that a higher percent return can be obtained at the 30 cm spacing than at the 15 cm spacing. Once nitrogen is sufficient, there is no effect of nitrogen on percent return.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was conducted at the Bixby Research Station in Northeast Oklahoma. It examined various nitrogen and spacing combinations to determine if nitrogen and spacing had an effect on quality of broccoli. The study also sought to begin to suggest combinations of nitrogen and spacing that would maximize yield under Oklahoma conditions.

Quality aspects of broccoli which were studied were stalk shear force and stalk diameter. The following conclusions may be suggested about these quality factors.

Within-row spacing has little or no effect on stalk shear force. Deficient nitrogen by itself is not enough to create a difference in stalk shear force. Low nitrogen in combination with other stresses such as water deficits or high temperatures may result in a difference in stalk shear force.

Stalk diameter is smaller at the 15 cm spacing than at the 30 cm spacing. Once nitrogen is adequate, nitrogen has no effect on stalk diameter.

Yield factors which were studied were cull production, marketable head production, average marketable head weight, days to first harvest, uniformity and percent return. The following conclusions may be suggested about the effect of nitrogen and spacing on these yield related factors. Cull production is greater at the 15 cm spacing than at the 30 cm spacing. Increased nitrogen reduced cull production especially at the 15 cm spacing.

When nitrogen is sufficient there is greater marketable head production at the 15 cm spacing than at the 30 cm spacing. There is a tendency for a linear response to nitrogen on marketable head production primarily at the 15 cm spacing.

Average marketable head weight is greater at the 30 cm spacing than at the 15 cm spacing. There is a greater effect of nitrogen on average marketable head weight at the 30 cm spacing than at the 15 cm spacing.

Earlier harvest may be obtained at the 30 cm spacing than at the 15 cm spacing. Nitrogen rate had little effect on earliness of harvest.

Neither nitrogen nor spacing affected uniformity of harvest except in Fall 87 which favored the 30 cm spacing.

Percent return is greater at the 30 cm spacing than at the 15 cm spacing. Once nitrogen is sufficient nitrogen had no effect on percent return.

In addition to these yield and quality factors petiole nitrogen content was analyzed to determine if the nitrogen added was in fact being taken up by the plant. Spacing had no effect on petiole nitrogen content in fall broccoli. With spring broccoli there was higher petiole nitrogen content at the 30 cm spacing than at the 15 cm spacing. As nitrogen increased petiole nitrogen content increased until saturation was reached; then further increase in nitrogen rate had no effect.

The following recommendations may be made based on these studies:

In the case of 'Premium Crop' cultivar under typical Oklahoma growing conditions, fall broccoli would be recommended over spring broccoli. Excessive heat at the end of the spring growing season results in a large number of culls and lower production.

Once nitrogen is sufficient additional nitrogen is not beneficial and need not be added. It appears that sufficient nitrogen to maximize yield may be obtained in the 181 to 224 $kg \cdot ha^{-1}$ range. This is in agreement with a number of researchers (Cutcliffe 1968), (Hipp 1973), (Gorski and Armstrong 1985). This will however vary depending upon the particular environmental conditions present. Beverly et al. found adequate nitrogen to be around 141 $kg \cdot ha^{-1}$, but Dufault and Waters 1985 and Greenwood et al. 1980 suggested that rates above 224 $kg \cdot ha^{-1}$ would still give increases in yield.

More research is needed before a spacing recommendation can be made. Total marketable head production is greater at the 15 cm spacing but this must be weighed against higher cull production, lower percent return, lower average marketable head weight and greater labor and transplant expense. The 30 cm spacing produces fewer culls, earlier harvest, greater head weight, and less labor and transplant expense. Research could be conducted to combine the costs and potential profits to make a spacing recommendation.

Another area of potential research is to find out what factor combined with low nitrogen in Spring 88 to produce the nitrogen effect on stalk shear force. Low nitrogen by itself did not create a significant effect. Perhaps water or heat stress combined with the low nitrogen to produce the noted effect.

There is evidence that quality broccoli can be produced in Oklahoma.

A SELECTED BIBLIOGRAPHY

1. Aldrich, T.M., M.J. Snyder and T.M. Little. 1961. Plant spacing in broccoli. Calif. Agr. 15(12):10-11.

2. Arjona, H.E. 1980. Effect of plant spacing and nitrogen fertilizer levels on yield, leaf cholorphyll content and nitrate reductase activity of broccoli. MS thesis, Kansas State Univ.

3. Beverly, R.B., W.M. Jarrell and John Letey Jr. 1986. A nitrogen and water response surface for sprinkler-irrigated broccoli. Agron J. 78:91-94.

4. Bourne, M.C. 1980. Texture evaluation of horticultural crops. HortScience 15:51-57.

5. Chung, B. 1982. Effects of plant density on the maturity and once-over harvest yields of broccoli. J. Hort Sci. 59:79-85.

6. Chung, B. 1985. The effects of sowing time and plant density on the once-over harvest yields of broccoli. J. Hort Sci. 60:57-64.

7. Cutcliffe, J.A., D.C. Munro and D.C. MacKay. 1968. Effect of nitrogen, phosphorus, potassium and manure on terminal, lateral, and total yields and maturity of broccoli. Can. J. Plant Sci. 48:439-446.

8. Cutcliffe, J.A. 1971. Effects of plant populations, nitrogen, and harvest date on yield and maturity of single-harvested broccoli. HortScience 6:482-484.

9. Cutcliffe, J.A. 1972. Effects of plant spacing and nitrogen on incidence of hollow stem in broccoli. Can. J. Plant Sci. 52:833-834.

10. Cutcliffe, J.A. 1975. Effect of plant spacing on single-harvest yields of several broccoli cultivars. HortScience 10:417-419.

11. Cutcliffe, J.A. 1975. Cultivar and spacing effects on incidence of hollow stem in broccoli. Can. J. Plant Sci. 55:867-869.

12. Davis, David W., Mohamed Achaboun, and Mando A. Shehata. 1981. The influence of growing environment and storage duration on quality of fresh-pack cucumber pickles. J. Text. Studies 12:507-520.

13. Dufault, R.J. and L. Waters, Jr. 1985. Interaction of nitrogen fertility and plant populations on transplanted broccoli and cauliflower yields. HortScience 20:127-128.

14. Gorski, S.F. and Armstrong, D.M. 1985. The influence of spacing and nitrogen rate on yield and hollow stem in broccoli. Res-Circ-OhioAgric-Res-Dev-Cent. Wooster, Ohio: the Center Sept. (288) p. 16-18.

15. Greenwood, D.J., T.J. Cleaver, Mary K. Turner, J. Hunt, K.B. Niendorf and S.M.H. Loquens. 1980. Comparsion of the effects of nitrogen fertilizer on the yield, nitrogen content and quality of 21 different vegetable and agricultural crops. J. Agr. Sci., Cambridge 95:471-485.

16. Hipp, B.W. 1974. Influence of nitrogen and maturity rate on hollow stem in broccoli. HortScience 9:68-69.

17. Hoff, J.E. 1973. Chemical and physical basis of texture in horticultural products. HortScience 8:108-110.

18. Kramer, A. and A.S. Szczesniak (eds.). 1973. Texture measurement of foods. D. Reidel Publ. Co., Dordrect, Holland.

19. Lee, C.Y. and M.C. Bourne. 1980. Changes in grape firmness during maturation. J. Text. Studies 11:163-171.

20. Letey, J. W.M. Jarrell, N. Valoras, and R. Beverly. 1983. Fertilizer application and irrigation management of broccoli production and fertilizer use efficiency. Agron J. 75:502-507.

21. Lipton, Werner J.m and C. Max Harris. 1974. Controlled atmosphere effects on the market quality of stored broccoli (Brassica oleracea L. italica group) J. Amer. Soc. Hort Sci. 99:200-205.

22. Magnifico, Vitangelo, Vincenzo Lattanzio, and Giulio Sarli. 1979. Growth and nutrient removal by broccoli. J. Amer. Soc. Hort. Sci. 104:201-203.

23. Massey, P.H. Jr., James F. Eheart, R.W. Young, and G.E. Mattus. 1962. The effect of soil moisture, plant spacing, and leaf pruning on the yield and quality of broccoli. Proc. Amer. Soc. Hort. Sci. 81:316-323.

24. Palevitch, D. 1970. Effects of plant population and pattern on yield of broccoli (Brassica oleracea var. italica) in single harvest. HortScience 5:230-231.

25. Pitt, R.E. 1984/85. Stress-strain and failure characteristics of potato tissue under cyclic loading. J. Text. Studies 15:131-156.

of plant density, spatial arrangement and sowing date on yield and head characteristics of a new form of broccoli. J. Hort. Sci. 59:79-85.

27. SAS Institute Inc. 1985. SAS Introductory Guide for Personal Computers, Version 6 Edition. Cary, NC:SAS Institute Inc.

28. Thompson, R.L., H.P. Fleming, D.D. Hamann amd R.J. Monroe. 1982. Method for determination of firmness in cucumber slices. J. Text. Studies 13:311-324.

29. Ware, George W. and McCollum J.P. 1980. Producing Vegetable Crops. The Interstate Printers and Publishers, Inc. Danville, Illinois.

30. Zink, F.W. 1968. Hollow stem in broccoli. Calif. Agr. 22(1):8-9.

31. Zink, F.W. and D.A. Akana. 1951. The effect of spacing on the growth of sprouting broccoli. Proc. Amer. Soc. Hort. Sci.58: 160-164.

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