CULTURAL PRACTICES FOR MECHANICALLY HARVESTED PAPRIKA

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CULTURAL PRACTICES FOR MECHANICALLY HARVESTED PAPRIKA

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INTRODUCTION

Sweet paprika is a major international spice commodity. The banning of artificial coloring substances in the United States and other countries has increased demand for paprika oleoresin. Color additives of plant origin are important as ingredients of many food products. Paprika provides a coloring medium for sausage and other meat products, salad dressings, pre-cooked food, condiment mixtures, catsup, and other processed food. Domestic buyers are interested in reducing dependence on imports, and some field-crop growers in the southwestern United States are trying paprika as an alternative crop. However, high labor requirements for picking the fruit by hand are a major drawback to increasing production. A mechanical paprika harvesting system is being developed with a modified cotton stripper, but efficient harvest mechanization also requires establishment of complementary horticultural practices. The studies were conducted with the following objectives:

1. Identify a within-row spacing for paprika which will maximize marketable yield per hectare while minimizing plant size and lodging so as to facilitate mechanical harvesting.
2. Compare raw seed, primed seed, and transplants for effects on methods of stand establishment, plant morphology, and yield of paprika pepper.

3. Identify a rate of ethephon as a fruit ripening agent, with and without calcium, to increase yields of red fruit without causing premature fruit abscission and defoliation.

CHAPTER I

WITHIN-ROW SPACING EFFECTS ON TRAITS OF IMPORTANCE TO MECHANICAL HARVEST IN PAPRIKA PEPPERS

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Additional index words. Plant populations, lodging, and plant size

Abstract: Several within-row spacings (WRS) were tested on paprika peppers (Capsicum annuum L.) grown at a standard between-row spacing of 0.9 m. The objective was to maximize marketable yield per hectare while minimizing plant size and lodging so as to facilitate mechanical harvest. Total and marketable fruit dry weights per m^2 decreased linearly as WRS increased from 5 to 25 cm in 1990. The 20 and 25 cm WRS produced undesirably massive plants with a high rate of lodging. Fruit yields were unaffected by WRS of 5, 10, and 15 cm in 1991, but lodging and stem dry weight data continued to favor the higher populations. Two experiments performed without thinning in 1992 produced WRS comparisons of about 4.5 vs. 8 cm and 7 vs. 11 cm, respectively. Stem dry weights were highest with the wider WRS, but marketable fruit dry weights per m^2 and lodging percentages were unaffected by WRS in either 1992 study. A target WRS of 10 cm (about 11 plants/m^2) is recommended for paprika intended for mechanical harvest. Net WRS<10 cm are preferable to those >10 cm.

Paprika plant development and yield are affected by row spacing and plant arrangement (Somos, 1984). Young and True (1913) recommended planting paprika in rows 0.9 to 1.2 m apart, with plants 30 to 46 cm apart within the rows. Such low populations facilitated hoeing and hand harvesting, but are not necessary with modern cultural practices and mechanical harvesters. Palevitch (1969), in Israel, conducted a trial of sweet pepper for single harvest of red fruits for dehydration. Palevitch thinned direct-seeded plants to 20 cm apart within rows at between-row spacings of 20, 40, and 60 cm. The spacing of 20 cm between rows produced the highest total yield and the highest yield of red fruits. Sundstrom et al. (1984) published a study involving spacings for mechanically harvested Tabasco pepper (*Capsicum frutescens* L.). They obtained linear increases in red pepper yields as WRS decreased from 81 to 10 cm. Sundstrom et al. (1984) also found the percentage of machine harvested red Tabasco peppers in respect to green and orange fruit was better with closer spacing.

A close spacing of the plants in the row (about 15 plants per meter) is an important factor in shaping the plants for efficient mechanical harvest (Wolf and Alper, 1984) without affecting yield potential for paprika (Palevitch and Levy, 1984). The closer spacing will produce a taller plant (Kovalchuk, 1983; Marshall, 1984; Palevitch and Levy, 1984) which will make it easier for a mechanical harvester to get under the fruit (Palevitch, 1978). Closer spacing also decreased the number of lateral shoots below the main branch (Palevitch, 1978; Palevitch and Levy, 1984) and produced smaller plants in terms of lateral branches (Thomas et al., 1982) which will increase the efficiency of the harvester (Palevitch and Levy, 1984). Moreover, lodging of the branches may be reduced by the support of adjacent plants produced by closer planting (Sundstrom et al., 1984).

Sundstrom et al. (1984) also reported much more damage from mechanical harvesting on Tabasco plants spaced at 81 cm in rows than on plants spaced at 10 cm in rows.

Our objective was to compare several within-row spacings to maximize yield per hectare of marketable oxblood fruit while minimizing plant size and lodging so as to facilitate mechanical harvesting of paprika peppers.

Field experiments were conducted at the Caddo Research Station, Fort Cobb, Okla. during 1990-1992 and at S & S Farms, Hydro, Okla. in 1992. The Cobb fine sandy loam (Alfisol) at Fort Cobb was furnished with a broadcast, preplant-incorporated application of 40N-45P-112K ($kg\cdot ha^{-1}$) in 1990; 72N-24P-46K ($kg\cdot ha^{-1}$) in 1991; and 50N-56P-0K ($kg\cdot ha^{-1}$) in 1992, based on soil tests and OSU recommendations. The Pond Creek silt loam (Mollisol) at Hydro was prepared with a broadcast, preplant-incorporated application of 56N-12P-46K ($kg\cdot ha^{-1}$). One topdressing was made each year at first flowering to supply 45 $kg\cdot ha^{-1}$ of N (not done at Hydro).

Weeds were controlled with preplant-incorporated napropamide at 1.7 $kg\cdot ha^{-1}$ and cultivation at Hydro and Fort Cobb in all years. Sprinkler irrigation was provided based on subjective soil observations at Fort Cobb and no irrigation was provided at Hydro.

'Oklahoma Paprika 50', an advanced breeding line with an upright growth habit, was direct seeded with commercially primed seed (Kamterter, Lincoln, Neb.; 1990 and 1991) or raw seed (1992). Between-row spacing was kept standard at 0.9 m. Planting was on 11 Apr. 1990, 15 Apr. 1991, and 8 Apr. 1992 at Fort Cobb and on 10 Apr. 1992 at Hydro. Thinning was done on 22 May and 5 June in 1990 and on 21 May and 10 June in 1991. No thinning was done in 1992. Harvest was on 20 Nov. 1990, 13 Nov. 1991, and 13 Nov. 1992 at Fort Cobb and on 9 Nov. 1992 at Hydro.

In 1990 simulated plug-mix planting was used with 3-6 seeds sown in clumps at the desired WRS of 5, 10, 15, 20, and 25 cm, followed by thinning to one plant per clump. In 1991, due to lack of positive plant characteristics the larger WRS (20 and 25 cm) were not repeated. Seeds were mechanically planted at about 100 per m of row, followed by thinning to the desired WRS of 5, 10, and 15 cm. In 1992, an effort was made to use practices that a grower could use to eliminate hand thinning and target the most promising WRS (5 or 10 cm). In 1992 at Fort Cobb all rows were mechanically planted at the same rate as in 1991, but half the rows were planted with blended 50 % live seed : 50 % dead seed (by weight). No thinning was done. The average WRS produced were 4.5 and 8 cm. At Hydro in 1992 seeds were mechanically planted at rates of 2.5 to 3.4 kg·ha^{-1}. No thinning was done. The average WRS produced were 7 and 11 cm.

Harvest occurred after a frost in each year to simulate grower practice. Three procedures occurred just before harvest: a) lodged plants were counted in 3-to-4 m row sections; b) uprooting resistance was measured on four plants per plot using a cable puller, milk scale, and a lever based on a fulcrum (not done in 1990); and c) three or four plants per plot were sampled for morphology data. These plants were excavated with a spade at a 20 cm radius to a depth of about 20 cm. At harvest, plants in 3-to-4 m row sections were cut off by hand at soil level, counted, and returned to the lab for defruiting. Fruits which were orange, green, bleached, or excessively infested with fungi were classified as culls. Plant materials were dried at 48C for at least 7 days before weighing.

The design was a randomized complete block with four (1990) or six (1991 & 1992) replications. Plots were 9 m long at Fort Cobb and 6 m long at Hydro. Data were evaluated by analysis of variance procedures. Main effects of spacing were partitioned into linear, quadratic, cubic, and quartic components in 1990 and into linear and quadratic components in 1991 using single degree-of-freedom orthogonal contrasts.

Final plant stands (no./m^2) were significantly different among treatments in all experiments as expected (Table 1).

Stem dry weights per plant showed a significant linear increase as WRS increased in 1990 and 1991 (Table 1). Main effects of WRS on stem dry weight also were significant at both locations in 1992. Stem diameters showed a significant linear increase in 1990, and a significant linear and quadratic increase in 1991 as WRS increased (Table 1). Main effects of WRS on stem diameter also were significant at both locations in 1992.

Root dry weights increased linearly as WRS increased in 1990 and 1991 (Table 1). Main effects of WRS on root dry weight also were significant at both locations in 1992. Shoot : root ratio also showed significant increases as the

WRS increased in three out of four experiments (Table 1). Uprooting resistance was unaffected by WRS $\leq$ 15 cm (data not presented).

The total number of fruits per plant increased as the WRS increased in 1990 and 1991 (Table 1). The total fruit weight per plant showed a significant linear and quadratic increase in 1990 and a significant linear increase in 1991 as WRS increased. Main effects of WRS on total fruit weight per plant were significant at Hydro but not at Fort Cobb in 1992 (Table 1). The percent of total fruit weight due to marketable fruits per plant showed a significant linear and cubic response only in 1990 and a nonsignificant response in the other years as the WRS increased (Table 1).

As the WRS increased from 5 to 15 cm or more, the percent of lodged plants increased, with a significant linear, quadratic, and quartic response in 1990 and a significant linear and quadratic response in 1991 (Table 2). There were no significant effects of WRS on lodging in 1992.

The number of marketable oxblood fruits per m^2 decreased in two of the four experiments as WRS increased (Table 2). However, WRS affected the weight of marketable fruits per m^2 only in 1990, when fruit weight declined linearly as WRS increased (Table 2). The total weight of fruits harvested per m^2 also decreased as WRS increased only in 1990 (Table 2). The percent of total fruit weight due to marketable fruits was unaffected by spacing in all experiments (Table 2).

The “ideal” plant type for mechanical harvesting might have upright principal stems with little base branching

(Thomas et al., 1982; Palevitch and Levy, 1984) and would maintain a reasonable yield (Marshall, 1984). Marshall (1984) showed that close spacing of the plants caused them to grow taller with fewer, more flexible branches and higher fruit placement.

Stoffella and Bryan (1988) also found with bell peppers that stem diameters increased due to decreasing competition with lower plant populations as in our experiments. Stoffella and Bryan (1988) found that with closer spacing, there was higher fruit placement on the plant and theorized that this might increase lodging. But in our experiments, the plants with larger WRS (WRS > 10 cm) showed an increase in lodging (Table 2).

The linear increase in shoot : root ratio as plant spacing increased in these experiments was also reported by Stoffella and Bryan (1988) with bell peppers. The higher shoot : root ratios seemed to show a relationship with higher rates of plant lodging. Stoffella and Bryan (1988) suggested that at higher plant populations, a proportionally larger root system to shoot mass is required to improve water and nutrient uptake due to higher root competition between plants.

The total weight of fruits harvested per plant usually was smallest at the closest WRS (Table 1). Ahmed (1984) and Kovalchuk (1983) showed that although each plant has fewer fruits at close WRS, a grower compensates by having more plants per area. Sundstrom et al. (1984), Batal and Smittle (1981), and Palevitch (1969) also found improved yield per m^2

with closer spacing. There seemed to be a range between 5 and 15 cm WRS where the total weight of fruits harvested ($g \cdot m^{-2}$) was not significantly affected by spacing (Table 2). Wider WRS (20 and 25 cm) produced decreases in total and marketable fruit weight per m^2 in 1990. Also, lodging percentages seemed to rise sharply at WRS ≥ 15 cm (Table 2).

The 68-79 percent of total fruit weight due to marketable fruits which we obtained in 1990 and 1992 is close to the 80-90 percent maturity suggested by Somos (1984) for effective mechanical harvest. Late summer hail storms damaged the plants at Fort Cobb in 1991. The hail knocked off some of the fruits (especially the larger, more mature fruits), but the plants responded by setting on a new flush of growth. The late fruit set was unable to mature before frost. The damage to mature fruits is the probable reason for the low percentage of total fruit weight due to marketable fruit in 1991. Thomas et al. (1982) found that decreasing the spacing of Tabasco pepper increased the percent red fruit, but there were no significant differences in percent marketable fruit in these experiments.

A target WRS of 10 cm is recommended for paprika pepper fields intended for mechanical harvest which agrees with Thomas et al. (1982) and Marshall (1984). Net WRS < 10 cm are preferable to those >10 cm, as wider WRS are likely to result in larger plants and more lodging.

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Table 1. Morphology and fruiting characteristics per plant of paprika peppers in response to within-row spacing.[z]

Spacing (cm)	Final stand (no. m^{-2})	Stem dry wt. (g/plant)	Root dry wt. (g/plant)	Shoot: root ratio	Stem diameter (mm)	Total fruits per plant Number	Total fruits per plant Weight (g)	Total fruits per plant % by wt. which were marketable
				1990				
5	20	7	2.1	3.4	8.0	6	8	97
10	9	12	3.7	3.3	10.8	14	18	89
15	7	19	5.3	3.5	12.8	18	30	88
20	5	26	6.4	4.3	14.9	21	37	94
25	4	31	7.2	4.1	16.3	26	36	83
	L**,Q**,C**,QT**	L**	L**	L**,C*	L**	L**	L**,Q*	L**,C**
				1991				
5	19	4	1.8	2.3	5.9	4	3	36
10	10	6	2.3	2.8	7.7	5	4	38
15	7	7	2.5	2.8	8.2	7	6	44
	L**,Q*	L**	L**	L**	L**,Q**	L**	L**	NS
				Ft. Cobb, 1992				
5 [y]	25	4	1.5	2.4	5.6	4	5	86
10	14	7	2.3	3.1	7.5	5	7	82
	**	**	*	*	**	NS	NS	NS
				Hydro, 1992				
5 [y]	16	20	3.9	5.0	10.1	15	27	71
10	10	42	8.9	4.8	14.2	28	58	79
	**	**	**	NS	**	NS	*	NS

[z] Data in this table (except for final stand) were obtained from individual plant samples (three per plot). [y] Target spacing. Linear (L), quadratic (Q), cubic (C), and quartic (QT) effects of WRS were tested. The highest order significant response is shown.
NS, *, ** Nonsignificant or significant at $P=0.05$ or $P=0.01$, respectively.

Table 2. Lodging and yield of paprika peppers in response to within-row spacing.[z]

Spacing (cm)	Final stand (no. m^{-2})	Lodging (%)	Marketable oxblood fruit (no. m^{-2})	Marketable oxblood fruit ($g \cdot m^{-2}$)	Total wt. of fruit harvested ($g \cdot m^{-2}$)	Percent of total fruit wt. due to marketable fruit
1990						
5	20	7	72	130	191	68
10	9	13	55	96	140	68
15	7	32	52	106	156	68
20	5	29	46	91	138	66
25	4	33	45	85	124	69
	L**,Q**,C**,QT**	L**,Q*,QT**	L**,Q*	L**	L**	NS
1991						
5	19	9	14	25	62	41
10	10	10	12	22	55	38
15	7	22	11	21	53	40
	L**,Q*	L**,Q*	NS	NS	NS	NS
Ft.Cobb, 1992						
5 [y]	25	7	37	76	101	74
10	14	12	29	68	96	71
	**	NS	*	NS	NS	NS
Hydro, 1992						
5 [y]	16	36	118	362	479	75
10	10	35	119	318	399	79
	**	NS	NS	NS	NS	NS

[z] Data in this table obtained from a per area basis. [y] Target spacing. Linear (L), quadratic (Q), cubic (C), and quartic (QT) effects of WRS were tested. The highest order significant response is shown.

NS, *, ** Nonsignificant or significant at _P_=0.05 or _P_=0.01, respectively.

CHAPTER II

MORPHOLOGY AND YIELD OF PAPRIKA PEPPER IN RESPONSE TO METHOD OF STAND ESTABLISHMENT

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Additional index words. priming, transplants, and mechanical harvesting

Abstract: Raw seed, primed seed, and transplants were compared for effects on stand establishment, plant morphology, and yield of paprika pepper (*Capsicum annuum* L.). Raw seed seemed satisfactory for stand establishment, although primed seed had the potential to provide better initial stands. When populations were equalized, there were few differences in plant growth, plant morphology, or fruit yield attributed to seed treatment. Morphology of plants established by direct seeding generally was favorable for mechanical harvest. Use of transplants did not result in higher marketable fruit yields than direct seeding in two out of three years. When compared to plants established by direct seeding, three trends were consistent across all three years for plants established by transplanting: a) they were more massive; b) they had larger vertical fruiting planes; and c) they had more branches. These traits would increase the difficulty of mechanical harvest and would create the potential for more trash in the harvested product. Thus, transplanting is not recommended for stand establishment of paprika intended for mechanical harvest.

There is little current information on stand establishment for paprika pepper. Most of the published studies on stand establishment for *C. annuum* involve bell pepper. While there are some similarities, bell pepper production involves different cultural systems as compared to paprika production.

In particular, bell peppers ordinarily are harvested by hand, while the developing Oklahoma paprika industry is based on mechanical harvesting. We are working to develop complementary cultural practices for efficient harvest mechanization in paprika.

Some of the first Oklahoma paprika growers established fields both by direct seeding and by transplanting. We observed differences in plant morphology among these fields. Plant morphology may have a significant impact on efficiency of mechanical pepper harvest (Marshall, 1984). However, we were unable to find studies relating method of stand establishment to morphology of paprika pepper. Work with *C. annuum* has revealed some general aspects of stand establishment.

Seed priming can increase germination rates (O'Sullivan and Bouw, 1984; Sundstrom and Edwards, 1989; Leskovar et al., 1990) and percentages (Saxena and Singh, 1987) and can result in more uniform emergence especially at lower temperatures (Saxena and Singh, 1987). But priming seems to inhibit some aspects of seed metabolism during germination (Sundstrom and Edwards, 1989). Seed priming can improve emergence and shorten the time from sowing to emergence (Bradford et al., 1990). Hypocotyl development can be advanced 7 days (Sundstrom and Edwards, 1989). A more uniform plant development rate was observed with primed seed (Perl and Feder, 1981). Sundstrom et al. (1987) found that the use of untreated seed produced higher stand percentages than the use of primed seed with Tabasco peppers (*Capsicum frutescens* L.).

The increases in germination and radical emergence rates do not necessarily increase seedling emergence percentages (Bradford et al.,1990).

Early production of peppers can be aided by the use of seed priming and transplants (Leskovar and Cantliffe, 1993; Sundstrom et al., 1987; Rivas et al., 1984). While early production in paprika peppers is not as important as in bell peppers, the extended season may make a difference in the total yield (Leskovar and Cantliffe, 1993).

At suboptimal soil temperatures, seed priming also allows for faster seedling development (O'Sullivan and Bouw, 1984; Rivas et al., 1984).

The total yield from older (35 days) transplants was higher than the yield of direct seeded pepper crops (Ghate et al., 1984). Fawusi (1978) proposed that the reduction in yield with direct seeding was due to delayed seedling emergence and impaired growth of the young plants. Sundstrom et al. (1987) found that Tabasco pepper stands were unaffected by seed treatments, but use of KNO_3-primed seed resulted in the highest percent red fruit indicating accelerated maturity compared to use of untreated seed.

Salt solutions can efficiently prime seeds without reducing final germination percentages (Smith and Cobb, 1991). The efficacy of a given salt solution is dependent on both the osmotic potential of the solution and the duration of the treatment (Smith and Cobb, 1991). Surface-dried treatments showed the fastest germination rate (Rivas et al., 1984).

Direct seeding of peppers allows for the development of a strong taproot. The taproot usually is damaged when transplanting (Weaver and Bruner, 1927). Plants grown from primed and raw pepper seed showed variable root growth compared to the more uniform early growth of transplants. The transplants produced superior plant growth and productivity was increased by changing the balance of growth between root and shoot after fruit set (Leskovar et al., 1990).

The high cost of labor and transplants at close spacing and the limited availabity of primed seed will restrict the use of these techniques for stand establishment of paprika. The profitability is affected by the lower expenses of growing direct seeded paprika due to decreased labor costs (Somos, 1984) and decreased need for specialized equipment. Economics and availability of labor are going to be strong influences on paprika pepper production in Oklahoma.

Our objective was to compare raw seed, primed seed, and transplants for effects on stand establishment, plant morphology, and yield of paprika pepper.

Field experiments were conducted at the Caddo Research Station, Fort Cobb, Okla. during 1990, 1991, and 1992. The Cobb fine sandy loam (Alfisol) at Fort Cobb was furnished with a broadcast, preplant-incorporated application of 40N-45P-112K ($kg\cdot ha^{-1}$) in 1990; 72N-24P-46K ($kg\cdot ha^{-1}$) in 1991; and 50N-56P-0K ($kg\cdot ha^{-1}$) in 1992, based on soil tests and OSU recommendations. One topdressing was made each year at first flowering to supply 45 $kg\cdot ha^{-1}$ of N. Weeds were controlled with preplant-incorporated napropamide at 1.7 kg·ha^{-1} and cultivation. Sprinkler irrigation was provided based on subjective soil observations.

Raw or commercially primed seeds (Kamterter, Lincoln, Neb.) were used for direct seeding in 1990 and 1991; only raw seeds were used in 1992. Transplants were grown in peat-lite mix in flats with inverted pyramid cells (1990) or in bulk benches (1991 and 1992). Desired field spacings were 0.9 m between rows and 0.1 m between plants within rows. Direct seeded plots were not thinned in 1990 because stands approached the desired density. Stand counts were performed in direct seeded rows on 21 May 1991, followed by thinning on 10 June. Direct seeded rows were thinned on 12 June 1992.

Seed of 'Oklahoma Paprika 50', an advanced breeding line with an upright growth habit, was sown in a greenhouse on 6 Mar. 1990, 4 Mar. 1991, and 12 Mar. 1992 for transplant production. Transplants were set in the field on 8 May 1990, 24 Apr. 1991, and 24 Apr. 1992. Direct seeding occurred on 12 Apr. 1990, 15 Apr. 1991, and 8 Apr. 1992 at 2-3 kg·ha^{-1}. Plots were 9 m long. The design was a randomized complete block with five (1990) or six (1991 and 1992) replications.

Harvest occurred after a frost to simulate grower practice. Three procedures occurred just before harvest: a) lodged plants were counted in 4-to-6 m row sections; b) uprooting resistance was measured on three or four plants per plot using a cable puller, milk scale and a lever based on a fulcrum; and c) three plants per plot were sampled for plant morphology data. At harvest, plants in a 3 m section of each plot were cut off by hand at soil level, counted, and returned to the lab for defruiting. Fruits which were orange, green, bleached or excessively infected with fungi were classified as culls. Plant materials were dried at 48C for at least 7 days before weighing.

Data were evaluated with an analysis of variance. Orthogonal contrasts were used where appropriate to compare stand establishment methods.

1990: Stands did not differ among treatments (Table 3). Stem dry weights of plants established by raw seed were significantly larger than those of plants established by primed seed. Use of transplants also resulted in more massive stems than direct seeding (Table 3). Lodging was increased and uprooting resistance was decreased in plants established by transplanting as compared to plants established by direct seeding. There were no differences in lodging and uprooting within direct seeded treatments.

Fruit production was unaffected by the method of stand establishment. The percent of total fruit weight due to marketable fruit also was not changed by the planting methods (Table 3).

Direct seeding treatments produced plants with higher first branches than those transplanted (Table 4). However, plants established by transplanting had the highest fruit attachment (Table 4). Highest plant part, first fruit attachment, and main stem fork heights were unaffected by the method of establishment. The transplants produced plants with more total branches than the seeded treatments

(Table 4). Number of main branches at the main stem fork and vertical fruiting plane were unaffected by the method of stand establishment.

1991: Primed seed gave better initial stand establishment than raw seed (40 and 53 plants/m^2, respectively). Thinning equalized the seed treatments final stands to 10 plants/m^2, which was significantly lower than the transplants (11 plants/m^2). Use of transplants resulted in more massive stems than direct seeding, as in 1990. Method of stand establishment did not affect lodging of the plants. Plants established by raw seed showed a lower uprooting resistance than plants established by primed seed (Table 3).

The number and weight of marketable oxblood fruit and the total weight of fruits harvested were highest in plants established by transplanting (Table 3). Use of transplants also resulted in the highest percent of total fruit weight due to marketable fruits (Table 3).

Height of first branch was unaffected by the method of stand establishment (Table 4). Use of transplants resulted in taller plants than direct seeding. There was no difference in the height of first fruit attachment with the treatments. However, the point of highest fruit attachment was farther from the soil in plants established by transplanting than in plants established by direct seeding. Height of the main stem fork, number of branches at the main fork, and total number of branches per plant were unaffected by method of stand establishment. Plants established by transplanting showed a significantly larger vertical fruiting plane than those established by direct seeding (Table 4).

The contrast between raw seed and primed seed was not significant for any measured plant morphological variable in 1990 or in 1991 (Table 4).

1992: Final stands did not differ among treatments. Stem dry weight, lodging, uprooting resistance, and fruit production were unaffected by method of stand establishment (Table 3).

Height of first branch, highest plant part, highest fruit attachment, and main stem fork were unaffected by method of stand establishment (Table 4). The raw seeded plants had a significantly higher first fruit attachment compared to the transplants. The number of branches at the main stem fork also was unaffected by method of stand establishment. Plants established by transplanting had more branches than plants established by direct seeding. The vertical fruiting plane did not differ with the treatments.

Although primed seed had the potential to provide better initial stands, as noted in several other studies (Leskovar et al., 1990; Sundstrom and Edwards, 1989; Bradford et al., 1990; Saxena and Singh, 1987; O'Sullivan and Bouw, 1984), raw seed seemed satisfactory for stand establishment in our studies. Others also have obtained acceptable results with raw seed as compared to primed seed (Bradford et al.,1990; Sundstrom et al., 1987). At harvest, plots established by transplanting had higher stands than plots established by direct seeding only in 1991, and then only by one plant/m^2

(11 vs. 10 plants/m^2). When populations were equalized (naturally or by thinning), there were few differences in plant growth attributable to seed treatment, in agreement with Sundstrom et al. (1987). The large number of plants in the initial stands of the seeded treatments in 1991 showed the large amount of seed that is needed to obtain a good stand. This could create a financial problem for the grower due to increasing seed cost, as well as the need for additional labor and machinery usage to thin the stands. Typically, however, the labor expenses for direct seeding are lower than those needed for transplants (Somos, 1984).

Plants established by transplanting usually had higher stem dry weights than plants established by direct seeding. Stem dry weight differences between the treatments might be due to different plant growth patterns. Stem weights of bell peppers established by transplants continued to increase throughout the growing season, while stem weights of plants established by primed seed reached a plateau and then decreased 72 days after planting (Leskovar and Cantliffe, 1993).

Plants established by transplanting had the most lodging in 1990, which was probably associated with the higher fruit attachment and greater number of branches as compared to plants established by direct seeding. Wolf and Alper (1984) suggested that when paprika plants are allowed to dehydrate in the field, the larger plants with heavy fruit might be more easily lodged by the wind. Marshall (1984) had found that more lodging occurred when plants were established with transplants than when they were established by direct seeding. However, even if lodging occurred with the plants established by direct seeding, the plants would be smaller and thus less likely to clog the harvester (Wolf and Alper, 1984).

Method of stand establishment significantly affected uprooting resistance in two out of three years (Table 3). Plants established by transplanting had lower uprooting resistance than plants established by direct seeding methods in 1990. Plants established with raw seed had lower uprooting resistance than plants established with primed seed in 1991. However, there was no general pattern with uprooting resistance in the studies.

Plant heights were close to "ideal" (Wolf and Alper, 1984; Marshall, 1984) in 1990, but continued to decrease in 1991 and 1992, possibly due to root-knot nematode (Meloidogyne hapla Chitwood) damage. We found no differences in overall plant height due to method of stand establishment, except in 1991 when hail may have been a factor. Palevitch (1978) and Sundstrom et al. (1987) also found no difference in plant height between direct seeded and transplanted paprika or Tabasco peppers, respectively.

The main stem fork should be 25 cm or higher for efficient fruit retrieval (Wolf and Alper, 1984). However, even at a lower branching height, the trial mechanical harvesting with a John Deere model 482 cotton stripper (Deere and Co., Moline, Ill.) in 1991 did not leave many fruits on the plants. The number of main branches (about 2.6 per plant) at the main stem fork was about the same for all treatments, which is close to the 2 per plant suggested by Wolf and Alper (1984). Use of transplants tended to produce plants with lower first branches than direct seeding, but differences were significant only in 1990. Plants established by transplanting had the largest total number of branches in 1990 and 1992, which may make fruit retrieval more difficult for the mechanical harvester by entrapping fruit (Marshall, 1984) and increasing trash (Wolf and Alper, 1984).

The first fruit attachment height was not significantly different among treatments in two out of three years, and was high enough for the harvester to get underneath the fruit. The point of highest fruit attachment was more responsive to method of stand establishment, with the transplants having the highest fruit attachment in 1990 and 1991 (Marshall, 1984). Thus the plants established by transplanting tended to have the largest vertical fruiting planes, showing that the fruit was dispersed throughout the canopy and not concentrated (Marshall, 1984). This trait could increase the difficulty of mechanical harvesting.

Transplanting consistently resulted in the largest total weight of fruits harvested, in agreement with several previous studies (Leskovar, 1990; Leskovar and Cantliffe, 1993; Motes et al., 1983; Sundstrom et al., 1987; Yaklich and Orzolek, 1977). However, differences were significant only in 1991. A hail storm occurred on 29 Aug. 1991, and apparently, fruit were more easily damaged under the smaller, less dense canopies produced by plants in the seeded treatments.

The number and weight of marketable fruits tended to be highest in the transplants as compared to raw or primed seeded treatments, in agreement with data of Sundstrom et al. (1987) with Tabasco peppers. However, disregarding the hail-damaged yield (1991), we found no significant increase of marketable fruits over that obtained from plants established by raw or primed seed. The hail damage was most evident in the decrease in percent of total fruit weight due to marketable fruits in 1991 as compared to 1990 and 1992. The plants responded to the late summer hail with a flush of new blooms, resulting in a large number of immature green fruit at harvest.

Raw seed seemed satisfactory for stand establishment in our studies, although primed seed had the potential to provide better initial stands. When populations were equalized (naturally or by thinning), there were few differences in plant growth, plant morphology, or fruit yield attributed to seed treatment. Economics will govern the choice between raw and primed seed. Morphology of plants established by direct seeding generally was favorable for mechanical harvest.

Use of transplants did not result in higher marketable fruit yields than direct seeding, except when hail damaged the plants (1991). Overall, morphology of plants established by transplanting was less favorable for mechanical harvesting than was morphology of plants established by direct seeding.

Contrasts of seed vs. transplants were not always significant at *P*=0.05 due to plot-to-plot variability. However, when compared to plants established by direct seeding, three trends were consistent across all three years for plants established by transplanting: a) they were more massive; b) they had larger vertical fruiting planes; and c) they had more branches. These traits would increase the difficulty of mechanical harvest and would create the potential for more trash in the harvested product. Thus, transplanting is not recommended for stand establishment of paprika intended for mechanical harvest.

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Table 3. Growth and yield responses of paprika peppers to method of stand establishment, Fort Cobb, Okla.

Method	Final stand (no./m^2)	Stem dry wt. (g/plant)	Lodging (%)	Uprooting resistance (N/plant)	Marketable oxblood fruit (no./m^2)	(g·m^{-2})	Total wt. of fruits harvest (g·m^{-2})	Percent of total fruit wt. due to marketable fruit
				1990				
Raw seed	11	11	11	98.1	48	93	144	64
Primed seed	13	9	6	107.9	51	87	140	62
Transplants	10	13	24	88.3	62	102	156	65
				Contrasts				
Seed vs. transplants	NS	**	**	**	NS	NS	NS	NS
Raw vs. primed seed	NS	*	NS	NS	NS	NS	NS	NS
				1991				
Raw seed	10	10	16	78.5	10	17	55	32
Primed seed	10	9	12	98.1	9	16	49	34
Transplants	11	16	14	98.1	43	61	124	48
				Contrasts				
Seed vs. transplants	*	**	NS	NS	**	**	**	**
Raw vs. primed seed	NS	NS	NS	*	NS	NS	NS	NS
				1992				
Raw seed	11	8	10	107.9	29	66	89	73
Transplants	11	10	14	117.7	41	80	108	73
				Main effect				
Seed vs. transplants	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, ** Nonsignificant or significant at P=0.05 or P=0.01, respectively.

Table 4. Plant morphology of paprika pepper in response to method of stand establishment, Fort Cobb, Okla.

	Height (cm), soil level to :					No. of main		
Method	First branch	Highest plant part	First fruit attachment	Highest fruit attachment	Main stem fork	branches at main stem fork	Total no. of branches	Vertical fruiting plane^z (cm)
				1990				
Raw seed	12	58	25	51	13	2.4	43	26
Primed seed	10	55	22	47	11	2.7	51	25
Transplants	6	58	22	55	9	2.4	66	33
				Contrasts				
Seed vs. transplants ^{y}	*	NS	NS	*	NS	NS	**	NS
				1991				
Raw seed	6	42	16	37	8	2.4	84	21
Primed seed	3	38	12	33	6	2.7	91	21
Transplants	5	50	14	46	7	2.4	107	32
Seed vs. transplants ^{y}	NS	*	NS	**	NS	NS	NS	**
				1992				
Raw seed	9	42	19	33	11	2.7	62	14
Transplants	4	41	14	35	11	2.9	88	21
Main effect								
Seed vs. transplants	NS	NS	*	NS	NS	NS	*	NS

^{z} Average vertical distance from first fruit attachment to highest fruit attachment.

^{y} The contrast "Raw seed vs. primed seed" was not significant at P=0.05 for any variable in this table in 1990 or in 1991.

$^{NS, *, **}$ Nonsignificant or significant at P=0.05 or P=0.01, respectively.

CHAPTER III

CALCIUM AND ETHEPHON EFFECTS ON PAPRIKA PEPPER FRUIT RETENTION AND FRUIT COLOR DEVELOPMENT

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Abstract: While ethephon [(2-chloroethyl)phosphonic acid] has increased yields of red fruits, its use as a pepper (Capsicum annuum L.) fruit ripening agent has been limited by premature fruit abscission and defoliation. We tested ethephon solutions of 0, 1500, 3000, 4500, and 6000 $\mu l \cdot liter^{-1}$ with or without 0.1 M $Ca(OH)_2$ as a one-time foliar application to field-grown paprika pepper in southwestern Oklahoma. There was a linear increase in fruit abscission with increasing ethephon rates in two out of three years, with or without added calcium. Ethephon at 6000 $\mu l \cdot liter^{-1}$ improved the percent of total fruit weight due to marketable fruits in two out of three years, primarily by decreasing the weight of harvested green fruits. However, ethephon never significantly increased the dry weight of harvested marketable fruits over that obtained from the control. There also was no effect of ethephon on the intensity of red pigment extracted from dehydrated marketable fruits. The only significant effect of $Ca(OH)_2$ was an undesirable increase in the retention of green fruits on the plants. Ethephon had little value as a fruit ripening agent for paprika under the conditions of our studies, and $Ca(OH)_2$ was not useful as an additive to ethephon sprays.

Mechanical harvesting of paprika is essential if expansion of production is to continue (Palevitch, 1978). Two prerequisites for mechanical harvest are the development of cultivars with characteristics adapted to mechanical harvesting (Werner and Honma, 1980) and cultural practices based on a single, destructive harvest (Palevitch, 1978). One cultural practice is the use of chemical ripening agents to accelerate (Batal and Granberry, 1982; Worku et al., 1975; Splittstoesser and Vandemark, 1971) and concentrate fruit maturity (Sims et al., 1970).

An 80-90 percent crop maturity will be needed to achieve an effective single mechanical harvest (Somos, 1984). The use of a chemical ripening agent may help to ripen the late fruit set during the mild Oklahoma fall conditions before frost. Ethephon has, without reducing yield (Sims et al., 1974), effectively concentrated red fruit maturity for a once-over harvest (Cantliffe and Goodwin, 1975; Robinson et al., 1968) and enhanced red color development in fruits (Knavel and Kemp, 1973). Color intensity of the fruit increased with the use of ethephon (Batal and Granberry, 1982; Worku et al., 1975). However, pepper leaf and fruit retention has decreased as ethephon rates increased (Conrad and Sundstrom, 1987; Batal and Granberry, 1982). Ethephon rates above 6000 $\mu l \cdot liter^{-1}$ caused severe fruit abscission (J.E. Motes, personal communication). It may be possible to decrease ethephon-induced abscission by the use of 0.1 M $Ca(OH)_2$ (Conrad and Sundstrom, 1987) with the formation of calcium pectate, the cementing substance between the cells (Addicott, 1968).

Our objective was to compare several rates of ethephon, with and without supplemental calcium, for efficacy in increasing yields of marketable oxblood fruit while minimizing premature fruit abscission.

Field experiments were conducted at the Caddo Research Station, Fort Cobb, Okla. during 1990 and 1991, and at S & S Farms, Hydro, Okla. in 1992. The Cobb fine sandy loam (Alfisol) at Fort Cobb was furnished with a broadcast, preplant-incorporated application of 40N-45P-112K ($kg \cdot ha^{-1}$) in 1990; 72N-24P-46K ($kg \cdot ha^{-1}$) in 1991; and 50N-56P-0K ($kg \cdot ha^{-1}$) in 1992, based on soil tests and OSU recommendations. The Pond Creek silt loam (Mollisol) at Hydro was prepared with a broadcast, preplant-incorporated application of 56N-12P-46K ($kg \cdot ha^{-1}$). One topdressing was made each year at first flowering to supply 45 $kg \cdot ha^{-1}$ of N (not done at Hydro).

'Oklahoma Paprika 50', an advanced breeding line with an upright growth habit, was direct seeded at 2-3 $kg \cdot ha^{-1}$ with 0.9 m between-row spacing. Plots were planted with raw seed on 11 Apr. 1990, 15 Apr. 1991, and 10 Apr. 1992. Plots were thinned to one plant every 0.1 m on 27 Jun. 1990 and 18 Jun. 1991. In 1992, plots averaged 1.4 plants every 0.1 m and were not thinned.

Weeds were controlled with a preplant application of napropamide at 1.7 $kg \cdot ha^{-1}$ and cultivation at Hydro and Fort Cobb in all years. Sprinkler irrigation was provided based on subjective soil observations at Fort Cobb and no irrigation was provided at Hydro.

The experimental design was a split-plot arranged in randomized blocks with three replications in 1990 and 1991. Main plots were ethephon solutions of 0, 1500, 3000, 4500, or

6000 $\mu l \cdot liter^{-1}$ sprayed on the pepper plants. Sub-plots (4 m long) were $Ca(OH)_2$ at 0.1 M, either added or not added to the ethephon solutions. Calcium was not used in 1992; the design was a 5 x 5 Latin square with the same ethephon rates previously used. Double-row plots were 4 m long in 1992. Treatments were applied on 16 Oct. 1990, 19 Oct. 1991, and 9 Oct 1992. Sprays were applied with a CO_2 backpack sprayer calibrated to deliver 74 $liters \cdot ha^{-1}$. Harvests were on 19 Nov. 1990, 13 Nov. 1991, and 9 Nov. 1992. Data areas were 2.5 m long in 1990 and 1991. Double-row plots were used in 1992, so data areas were decreased to 1.5 m long.

A single destructive harvest was made after a frost in each year to simulate grower practice. Plants were cut by hand at soil level, counted, and placed in burlap sacks. All fruits on the ground beside the data rows, including those which abscised during harvest, were collected and counted separately. Fruits were removed from the plants in the laboratory. Fruits which were orange, green, bleached, or excessively infested with fungi were classified as culls. Marketable oxblood fruits were leathery and partially-dried with a deep red color. Stems and leaves were replaced in burlap sacks. All plant material was dried at 48C for at least 7 days and weighed.

Representative samples of marketable fruits were analyzed for extractable red color in all years of the study. A composite sample consisting of 10% (by weight) random fruits from each of the four color categories, including calyxes, also was taken from each plot in 1992. A second sampling was made from marketable oxblood fruits, with calyxes removed. Dry fruit samples were ground in a Wiley mill to pass a 40-mesh screen and analyzed for red color according to Method 20.0 of the American Spice Trade Association (ASTA, 1968). Acetone extracts were analyzed for absorbency at 460 nm using a spectrophotometer (Spectronic 20, Bausch and Lomb, Rochester, N.Y. in 1990 and 1991; Shimadzu UV160A, Shimadzu, Kyoto, Japan in 1992).

There were no differences in plant stands among the plots in any of the experiments (data not presented).

Stem and leaf dry weight per plant showed no significant effect due to ethephon treatment (Tables 5, 6, and 7). The addition of calcium as $Ca(OH)_2$ at 0.1 M produced no significant effect on the stem and leaf dry weight per plant in 1990 (Table 5) and a significant increase in 1991 (Table 6).

The total dry weight of abscised fruits increased linearly as the rate of ethephon increased in 1990 and 1992 (Tables 5, and 7). Calcium had no significant effect on the total weight of abscised fruits in both years (Tables 5 and 6).

The total dry weight of harvested fruits decreased linearly as the ethephon rates increased in 1992 (Table 7). Calcium increased the total weight of the harvested fruits in 1991 (Table 6). The dry weight of marketable oxblood fruits showed a cubic decrease in response to the increasing rate of ethephon in 1992 (Table 7). Calcium had no significant effect on the marketable oxblood fruit weights (Tables 5 and 6). Ethephon rates or calcium had no effect on the dry weight of orange fruits per m^2 (Table 5, 6, and 7). The dry weight of green fruits decreased linearly in 1990 and cubically in 1992 in response to increasing ethephon rates (Tables 5 and 7). Calcium significantly increased the weight of harvested green fruits in both years (Tables 5 and 6). The weight of fruits which were bleached or infested with fungi showed a cubic response to increasing ethephon rates in 1991 (Table 6). Calcium showed no significant effect on the weight of fruits which were bleached or infested with fungi (Tables 5 and 6).

The percent of total fruit weight due to marketable fruits responded quadratically and cubically to increasing ethephon rates in 1991 and 1992, respectively with no response in 1990 (Tables 5, 6, and 7). Calcium showed no significant effect on the percent of total fruit weight due to marketable fruits. The marketable fruit color (ASTA) was not affected by the ethephon rates or the addition of calcium (Table 5, 6, and 7). The composite fruit color (only taken in 1992) also was not affected by the ethephon rates (Table 7).

The ethephon x calcium interaction was not significant for any of the variables measured (Tables 5 and 6).

The weight of abscised fruit increased with increasing rates of ethephon in two of three years. Similar responses have been reported for paprika by Batal and Granberry (1982), for sweet peppers by Cantliffe and Goodwin (1975), and for Tabasco peppers by Conrad and Sundstrom (1987). Ethephon with the addition of calcium as $Ca(OH)_2$ at 0.1 M reduced the amount of fruit abscision on Tabasco peppers as reported by Conrad and Sundstrom (1987), but did not significantly decrease the total weight of abscised fruit in our studies.

Ethephon treatments decreased the total dry weight of harvested fruits only in 1992. Cantliffe and Goodwin (1975) and Batal and Granberry (1982) reported decreases in pepper fruit yields with ethephon applications, but at lower rates (one 500 and two 500 $\mu l \cdot liter^{-1}$ sprays, respectively) perhaps because their plants were sprayed until runoff occurred.

Sims et al. (1970), Batal and Granberry (1982), and Cantliffe and Goodwin (1975) had all shown an increase in percent of total fruit yield due to red fruit following ethephon treatments. Ethephon rates of 6000 $\mu l \cdot liter^{-1}$ significantly improved the percent of total fruit weight due to marketable fruits in two out of three years in our studies, primarily by decreasing the dry weight of harvested green fruit. The use of calcium did not change the percent of total fruit weight due to marketable fruits.

Worku et al. (1975) and Batal and Granberry (1982) found that ethephon increased the marketable fruit color (ASTA), but there was no significant increase in our experiments. Calcium did not increase the marketable fruit color in either year.

Ethephon had been shown to increase the yield of red peppers by Cantliffe and Goodwin (1975) with Tabasco, Batal and Granberry (1982) with paprika, and Osterli et al. (1975) with bell peppers, but there was no overall positive effect in our experiments. The apparent increase in harvested marketable oxblood fruit weight at 1500 $\mu l \cdot liter^{-1}$ in 1990 and 1992 was not significant over the control. The addition of calcium did increase the total yield in 1991, but the increase was in nonmarketable fruits (Table 6). Thus, ethephon had little value as a fruit ripening agent under the conditions of our studies, and $Ca(OH)_2$ was not useful as an additive to ethephon sprays.

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Table 5. Growth and yield of paprika peppers in response to ethephon / $Ca(OH)_2$ treatments, Fort Cobb, Okla., 1990.

Variable	Dry wt., stems and leaves (g/plant)	Total dry wt. of abscised fruit $(g \cdot m^{-2})$	Fruit dry wts. at harvest $(g \cdot m^{-2})$					Percent of total fruit wt. due to marketable fruit	Marketable fruit color (ASTA)
			Marketable oxblood	Orange	Green	Bleached/ fungus	Total		
Ethephon (E) [z]									
0	8	24	80	5	8	20	114	70	217
1500	10	24	104	12	8	20	144	72	219
3000	9	27	90	11	6	20	127	70	225
4500	8	26	82	8	5	19	113	72	212
6000	8	37	66	7	4	16	93	72	216
E linear [y]	NS	*	NS	NS	*	NS	NS	NS	NS
$Ca(OH)_2$ at 0.1 M									
Not added	8	30	80	8	4	18	110	72	212
Added	9	24	88	9	8	20	126	70	224
Main effect	NS	NS	NS	NS	**	NS	NS	NS	NS
E x $Ca(OH)_2$	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Ethephon rate in $\mu l \cdot liter^{-1}$.

[y] Quadratic, cubic, and quartic effects of ethephon were not significant P=0.05.

NS, *, ** Nonsignificant or significant at P=0.05 or P=0.01, respectively.

Table 6. Growth and yield of paprika peppers in response to ethephon / $Ca(OH)_2$ treatments, Fort Cobb, Okla., 1991.

Variable	Dry wt., stems and leaves (g/plant)	Total dry wt. of abscised fruit ($g \cdot m^{-2}$)	Fruit dry wts. at harvest ($g \cdot m^{-2}$)					Percent of total fruit wt. due to marketable fruit	Marketable fruit color (ASTA)
			Marketable oxblood	Orange	Green	Bleached/ fungus	Total		
Ethephon (E) [z]									
0	10	22	23	7	28	5	63	36	198
1500	11	20	25	9	30	8	71	34	198
3000	9	18	22	9	29	4	64	34	193
4500	9	20	19	9	26	4	58	32	191
6000	9	20	27	8	24	5	64	41	190
E response [y]	NS	NS	NS	NS	NS	C*	NS	Q**	NS
$Ca(OH)_2$ at 0.1 M									
Not added	9	20	22	8	24	5	58	37	194
Added	10	20	25	9	31	6	70	34	195
Main effect	**	NS	NS	NS	**	NS	*	NS	NS
E x $Ca(OH)_2$	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Ethephon rate in $\mu l \cdot liter^{-1}$. [y] Linear, quadratic, cubic, and quartic effects of ethephon were tested. C*=Cubic effect significant at P=0.05. Q**=Quadratic effect significant at P=0.01.

NS, *, ** Nonsignificant or significant at P=0.05 or P=0.01, respectively.

Table 7. Growth and yield of paprika peppers in response to ethephon treatments, Hydro, Okla., 1992.

Variable	Dry wt., stems *and leaves* (g/plant)	Total dry wt. of abscised *fruits* ($g\ m^{-2}$)	Fruit dry wts. at harvest ($g\ m^{-2}$) Marketable oxblood					Percent of total fruit wt. due to marketable fruits	Fruit color (ASTA)[z] Composite	
			Marketable oxblood	Orange	Green	Bleached/ fungus	Total		Composite	Marketable
Ethephon (E)										
0	29	56	259	21	77	3	360	71	98	181
1500	30	72	277	19	43	4	342	80	107	183
3000	34	72	229	21	52	3	305	75	109	182
4500	27	105	204	22	43	2	270	75	106	197
6000	24	108	225	16	27	2	270	83	107	187
E response [y]	NS	L**	C*	NS	C**	NS	L**	C**	NS	NS

[z] Composite samples consisted of 10% (by weight) random fruits from each of the four color categories, including calyxes, from each plot. Calyxes were removed before the separate analysis of marketable fruits. American Spice Trade Association (ASTA) color units are reported.

[y] Linear (L), quadratic (Q), cubic (C), and quartic (QT) effects of ethephon were tested. The highest order significant response is shown.

NS, *, ** Nonsignificant or significant at P=0.05 or P=0.01, respectively.

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