



Plant Spacing/ Plant Population for Machine Harvest

College of Agriculture and Home Economics
Cooperative Extension Service
Agricultural Experiment Station

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Jerry Schickedanz (ex officio)

Dean
NMSU College of Agriculture and Home Economics
(505) 646-3748
jschicke@nmsu.edu

For more information, contact:

New Mexico Chile Task Force
Rich Phillips, Manager
New Mexico State University
Cooperative Extension Service
College of Agriculture and Home Economics
Box 30003, MSC 3AE
Las Cruces, NM 88003-8003
Phone: (505) 646-2353
Fax: (505) 646-8085
E-mail: rphillip@nmsu.edu



Plant Spacing/Plant Population for Machine Harvest^{1,2}

By Margery Paroissien and Robert Flynn³

Research Summary

Previous studies indicate that increasing plant density has a favorable effect on plant structural characteristics related to mechanical harvest efficiency. In the Southwest, paprika is typically direct-seeded and then thinned by a hand crew to the desired density. In this study, six thinning trials were executed to evaluate the effect of thinning treatment on final plant density, yield/acre, quality (level of extractable color) and plant structure (stem thickness, main fork angle, height of first fruiting position and plant height) of three paprika varieties commonly grown in the Southwest ('B-18', 'B-58' and 'Sonora'). Although the trials ranged in location, size, management and harvest method, the treatments at each location for each variety were consistent, with the exception of one treatment added the final year. Three thinning treatments were used in 2001 and 2002; two removed plants (8-inch and 4-inch in-row plant spacing) and one allowed all germinated seeds to develop into mature plants (no-thin). The latter treatment was included to determine whether thinning is even necessary. The commercially acceptable plant spacing before this study was 8 inches (19,600 plants per acre).

The final density achieved from a given thinning practice was highly variable across locations and years. Yield responses varied greatly by location, year and variety, but results indicate that a density achieved at a spacing that is nearly three times the standard density will not reduce yield. The level of extractable color was significantly reduced at densities greater than 100,000 plants per acre (smallest spacing) in two of the six studies, but not below where paprika processors pay growers a premium. In general, as in-row spacing was reduced (increasing plant density), stem thickness and main fork angle were reduced, while fruit and plant height were increased.

At this time, we recommend increasing plant populations on red chile and paprika that will be machine harvested to no less than an evenly distributed 40,000 plants per acre



¹ This article was reviewed by Rich Phillips, manager, New Mexico Chile Task Force and Stephanie Walker, Extension vegetable specialist, New Mexico State University, Las Cruces, and Ed Hughs, director, U.S. Department of Agriculture Southwestern Cotton Ginning Research Laboratory, Mesilla Park, N.M.

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³ Graduate research assistant, NMSU Department of Agronomy and Horticulture, Las Cruces, and Extension specialist, NMSU Extension Plant Sciences, NMSU Agricultural Science Center at Artesia, N.M. (rflynn@nmsu.edu).

(3 plants per foot). The results of these studies suggest that plant density near 80,000 plants per acre can be tolerated. Plant density less than 20,000 plants per acre would hinder efficient machine harvesting.

Background

The first machine chile pepper (*Capsicum* spp.) harvest in the United States was attempted in 1965 by Ernest Riggs of Las Cruces, NM (Marshall, 1997). During the following four decades, machine chile harvesters' evolution progressed slowly (Fullilove and Futral, 1972; Gentry, Miles and Hinz, 1978; Lenker and Nascimento, 1980; Wolf and Aper, 1984; Marshall, 1984a). Thirty-two years after the first attempted machine chile pepper harvest, the vast majority of harvesting was still done by hand (Marshall, 1997).

In the mid-1990s, the North American Free Trade Agreement's (NAFTA) impact on the Southwest sparked a strong interest in machine harvest, especially in New Mexico. There was a growing sense by the late 1990s that the state's chile production tradition was on the brink of collapse because of high domestic labor costs relative to those overseas. In 1998, the New Mexico Chile Task Force was created when the industry requested help from New Mexico State University's College of Agriculture and Home Economics (Diemer, Phillips and Hillon, 2002) to make the industry more efficient. Improvement in machine harvest efficiency was set as a primary task force goal to reduce the cost of commercial pepper harvest (Diemer, 1998, cited in Diemer et al., 2002).

Capsicum spp. covers a wide range of plant habits, making it difficult to design a single machine that can harvest all types (Marshall, 1984b). From existing work on machine harvest, a dozen major principles emerged leading to some machines designed for destructive once-over harvests and others for multiple picks. The open helix is the most popular design, used in more than 25% of chile harvesters worldwide (Marshall, 1997). The double open-helix principle appeared the most flexible in a harvest evaluation that encompassed many major commercial chile types (Marshall and Esch, 1986).

From a commercial viewpoint, the variation among *Capsicum* spp. is highly valuable. The different chile types available for production in New Mexico (long green and red, paprika, jalapeños and cayenne) offer farmers a broad marketing range including niche markets. For example, many paprika varieties are grown for their high carotenoid content. These compounds are extracted and used as a natural dye source for foods and cosmetics (Wolf and Aper, 1984).

Paprika's value is based on its level of extractable color or ASTA units, a measurement developed by the American Spice Trade Association (ASTA) and the Association of Official Analytical Chemists (Wall and Bosland, 1998). Biosynthesis of carotenoids, the compounds responsible for the deep-red, extractable pigment, is light dependent (Cavero, Ortega and Gutierrez, 2001). The Southwest's intense sun and long growing season provide a highly suitable climate for paprika production (Kahn, 1992). New Mexico growers take advantage of the circumstances to produce a high-quality product; paprika accounted for 38% of the state's red chile production on a dry weight basis in 2002 (U.S. Department of Agriculture, 2002).

For chile peppers, the greatest strides in machine harvest have occurred in red chile, paprika and jalapeños. Red chile and paprika offer a distinct advantage in machine harvest; pod damage is not a critical issue since the product typically is further processed into flakes or powder. Jalapeños, though sold as a fresh commodity, are easily adapted to machine harvest

because their smaller size and thicker walls make them resistant to damage. Fresh market green chile presents a greater challenge because damage to pods reduces marketability (Eastman, McClellan and Bagwell, 1996).

Red chile, paprika and jalapeños also exhibit structural characteristics that are conducive to machine harvest. For example, the principle stem of all three types is typically upright, not sprawling. A sprawling plant habit is undesirable for machine harvest because the harvester must gather and draw in the horizontal branches before it can strip the pods. An upright plant habit eliminates this requirement (Marshall, 1984b).

The calyx orientation for red chile and paprika also facilitates machine harvest. As the harvester strips up through the plant, the force exerted on the calyx of hanging fruit snaps it from the stem as the fruit is drawn upward. Erect fruits are more difficult to remove because the calyx is not forced against its orientation. Hanging, or pendant, fruit is characteristic of both red chile and paprika (Marshall, 1984b).

Several other factors constitute a generalized ideal plant habit for machine harvest. In addition to an upright habit with pendant fruit, the plants should have flexible stems. Rigid, brittle stems break easily when drawn upward by the harvester. Thin stems may be more flexible and less likely to snap off from the plant. Broken stems and other unwanted, machine-harvested plant material must be separated from desirable fruit before further processing. Fruit may remain attached to broken branches. In addition, extra labor is required to detach marketable fruit from the branches or, if the stems are discarded, a portion of the marketable chile is lost (Marshall, 1984b).

Branching angle of the plant is also an important consideration. A narrow branch angle is preferred. A wide fork angle, typical of cherry and bell peppers, can trap and crush fruit when pulled into a vertical position. A wide fork angle also can cause the main branches to break when drawn upward (Marshall, 1984b).

An ideal plant for machine harvest should have a minimal crown set (Marshall, 1984b). The height of the first fruit set should be roughly 4 to 10 inches (10-25 cm) above ground level (Marshall, 1984b; Wolf and Aper, 1984). An even distribution of pods throughout the canopy is preferred for machine harvest over a bottom-heavy set (Marshall, 1984b).

Total plant height is another important factor for machine harvest. Marshall (1997) and Wolf and Aper (1994) suggest that about 2 ft (60 cm) to 2.6 ft (80 cm) is optimum. This height would allow the harvester conveyor to fit under the canopy (Marshall, 1997) without pushing fruit above the harvester unit's reach. If plants are much taller, susceptibility to lodging or wind damage becomes a concern (Boese and Marshall, 1998).

Combining these individual factors into one ideal plant type provides a blueprint for plant breeders and should be considered with a particular type of machine in mind (Marshall, 1997). Harvest efficiency will improve by developing chile lines suitable for machine harvest. Although breeding programs are underway, no cultivars designated specifically for machine harvest have been released. Therefore, a short-term solution is needed while breeding efforts continue.

Certain architectural characteristics important for machine harvest of chile can be controlled through the cultural practice of plant spacing, which affects plant density. According to Marshall (1984b), plants grown at high densities are easier to harvest because they grow taller and the stems are more flexible. In machine harvest of tabasco peppers, fewer stems were broken during harvest at a plant spacing of about 4 inches (10 cm) compared to wider plant spacings (Sundstrom et al., 1984, cited in Decoteau and Graham, 1994).

Many researchers have evaluated the effect of plant density on yield for several *Capsicum* varieties (Marshall, 1984b, 1997; Motsenbocker, 1996; Decoteau and Graham, 1994; Holle, Veliz and Saunders, 1983; Stoffella and Bryan, 1988; Gaye, Jolliffe and Maurer, 1992; Cavero et al., 2001). In general, as density increases, yield on a per unit area basis increases to an upper limit. After this maximum is reached, only minor improvements in yield are achieved, or decreases in yield are realized.

In paprika production, it is important to determine how density affects carotenoid content. Because paprika is produced for color extraction, growers often are paid a premium for a product with high levels of extractable color. Only one study has evaluated how density changes correlate to color content of paprika. Cavero et al. (2001) found ASTA values decreased with increasing density. However, at the optimum density reported of roughly 60,700 to 80,940 plants/acre (150,000 to 200,000 plants/ha), ASTA units were still above 300, sufficiently high for quality standards.

Research

Research objectives

The objective of this research was to examine how yield, color and plant architecture are affected at plant densities higher than those typically used in Southwest Chile production. By including a natural thinning treatment (“no-thin”), this research was designed to determine whether thinning is necessary at all.

Hypothesis

This study’s hypothesis was that standard 8-inch spacing is too wide, and that equal-to-higher yields of high-quality paprika can be obtained through closer plant spacing and therefore reduced thinning. A secondary hypothesis was that reduced thinning should alter plant structure in ways that may improve machine harvest efficiency (i.e., decrease stem thickness and the angle of the main fork, and increase the height of the lowest setting fruit and overall plant height).

Materials and methods

Overview

This report describes thinning trials conducted during three years (2001-2003). Originally, the research was conducted at a commercial production level, with plots large enough to be machine harvested. In the following two years, similar studies were established on a smaller scale to supplement the data collection on yield/acre, extractable color and plant architecture as affected by thinning treatment. Due to size restrictions, small-scale plots were harvested by hand rather than machine. Each location/year will be referred to as a separate study because the trials varied in paprika variety, plot size, treatment establishment, harvest method and collected data (table 1).

Figure 1. Calculating plant density

- | | | | | |
|--|------------------------|-------------------------|--------------------------|-------------------------|
| 1. Choose bed (<i>right</i>): | 40 in. | 36 in. | 32 in. | 30 in. |
| 2. Count number of plants in the number of feet (<i>right</i>) that corresponds with chosen bed width. (Obtain counts at several field locations): | 2 ft 4 in.
(2.3 ft) | 2 ft 1 in.
(2.07 ft) | 1 ft 10 in.
(1.84 ft) | 1 ft 9 in.
(1.72 ft) |
3. Divide the number of plants by the footage.
 4. Multiply the average number of plants found above by 10,000 to determine plants per acre.

For bed widths other than those given, use the following procedure:

1. Divide 43,560 (square ft per acre) by the bed width (in feet) to obtain the number of row feet in an acre (row feet).
2. Obtain an average plant count in 3 feet of row at several field locations.
Average = $(15+15+17+19+19+20+21)/7 = 18$ plants in 3 feet
3. Divide the average plant count by the number of feet used in plant count (e.g. 3 feet to get the number of plants per foot)

Example, using 40-in. beds, center to center:

1. Determine row feet per acre.
 $40 \text{ in.} \div 12 \text{ in.} = 3.33 \text{ ft (bed width in feet)}$
 $43,560 \text{ ft}^2 \div 3.33 \text{ ft} = 13,081 \text{ row ft}$
 There are approximately 13,081 row feet in an acre that is 40" wide.
2. Obtain average of the plant counts sampled in 3-ft row sections throughout the field.
 If plant counts = 15, 15, 17, 19, 19, 20 and 21 plants per 3 row feet:
 Average = $(15+15+17+19+19+20+21) \div 7 = 18$ plants
 There are approximately 18 plants in 3 row feet.
3. Calculate density on an acre basis.
 $13,081 \text{ row ft per acre} \times 18 \text{ plants per 3 row ft} = 78,486 \text{ plants per acre}$

The plant density is approximately 78,486 plants/acre.

The following table shows plants per foot at various plant spacings and bed widths:

Plant Spacing (in)	Bed Width (inches)		
	40	36	30
	Calculated Plants per Foot		
1	12.0	12.0	12.8
2	6.0	6.0	6.4
4	3.0	3.0	3.2
6	2.0	2.0	2.1
8	1.5	1.5	1.6
10	1.2	1.2	1.3

Table 1. Description of thinning trials, 2001-2003.

Study	Variety	Bed	Plot size	Treatments (spacing)	Thinning crew	Harvest method	Data collected
Ft. Hancock 2001	'B-18'	40"	8 rows, 650-ft long	no-thin, 4", 8"	commercial	machine	final density, yield, ASTA, stem width, fork angle, plant height, fork height
Ft. Hancock 2002	'B-18'	40"	8 rows, 640 ft-long	no-thin, 4", 8"	commercial	machine	final density, yield, ASTA
Las Cruces 2002	'B-18'	40"	8 rows, 100 ft-long	no-thin, 4", 8"	commercial	hand	final density, yield, ASTA, stem width, fork angle, plant height
Las Cruces 2002	'Sonora'	40"	8 rows, 100 ft-long	no-thin, 4", 8"	commercial	hand	final density, yield, ASTA, stem width, fork angle, plant height
Hobbs 2002	'B-58'	36"	2 rows, 9 ft-long	no-thin, 4", 8"	non-commercial	hand	final density, yield, ASTA, stem width, plant height, fork height
Garfield 2003	'B-58'	38"	2 rows, 25 ft-long	no-thin, 2", 4", 8"	non-commercial	hand	final density, yield, ASTA, stem width, fork angle, plant height, fork height

Density, yield, and quality measurements

Final density (plants/acre). Plant counts were made at harvest time to determine the average density achieved with each treatment. This measurement was made by sampling three, 3-ft sections of row per plot. The average number of plants per 3-ft section was then estimated to an acre by using a direct proportion derived from the number of row feet per sampled area to the number of row feet per acre based on bed width (fig. 1).

Yield (dry lbs/acre). Yield/acre estimates also were made using the proportion of row feet per harvested area to row feet per acre based on bed width. The total area harvested varied among the studies (table 1). At Ft. Hancock, where chile was harvested by machine, dry yield was estimated from the fresh weight because the chile was taken to a processing plant after harvest and was unavailable for further tracking. A wet:dry ratio was determined from a sample of harvested material from each plot. The sample was weighed fresh, dried and reweighed. Each plot's dry:wet ratio was applied to the fresh weight of chile harvested from the corresponding plot. In the remaining studies, chile was harvested by hand, dried and weighed to determine a dry yield per plot that was extrapolated to an acre basis based on row-feet conversions.

ASTA. After yield samples were processed (i.e. dried and weighed), pods were removed at random to obtain at least 2 oz of sample from each plot for color analysis by ASTA method 20.1 (American Spice Trade Association, 1985). Whole pods with stem and seeds intact were ground into a fine, homogenous powder, collected after passing through a 1 mm sieve. A small amount of powder (0.08 g) was removed and mixed with 50 ml of acetone in an Erlenmeyer flask. This solution was incubated in the dark at room temperature for 16 hours.

Table 2. Densities achieved by thinning treatments

Location, year variety	Thinning treatment (inches)				Overall treatment effect ^a
	8	4	2 ^b	No-thin	p-value
Ft. Hancock, 2001 'B-18'	25,046 <i>b</i>	30,128 <i>b</i>	-	62,979 <i>a</i>	0.0021
Ft. Hancock, 2002 'B-18'	38,341 <i>c</i>	62,178 <i>b</i>	-	197,347 <i>a</i>	<0.0001
Las Cruces, 2002 'B-18'	30,205 <i>b</i>	42,154 <i>b</i>	-	11,9824 <i>a</i>	0.0010
Las Cruces, 2002 'Sonora'	27,882 <i>b</i>	34,188 <i>b</i>	-	11,3185 <i>a</i>	<0.0001
Hobbs, 2002 'B-58'	20,435 <i>b</i>	35,224 <i>b</i>	-	136,593 <i>a</i>	0.0002
Hobbs, 2003 'B-58'	21,022	20,524	21,741	39,388	0.0579
Garfield, 2003 'B-58'	20,265 <i>d</i>	37,385 <i>c</i>	46,120 <i>b</i>	84,553 <i>a</i>	<0.0001

^a Significance at $P \leq 0.05$ followed by mean separation of density by LSD.

Numbers with the same letter within a location/year/variety are not different at the 5% level.

^b 2-inch spacing only included at Hobbs-2003 and Garfield.

After incubation, 3 ml of solution were removed from each flask, mixed in a cuvette with 3 ml of acetone; the absorbency of the solution was measured with a spectrophotometer set at a 460 nm wavelength. This value was then used to calculate the ASTA units by the following formula:

$$\text{ASTA color} = \frac{\text{Absorbance of the sample extract} \times 16.4 \times I_f}{\text{Sample weight in grams}}$$

Plant architecture measurements

Stem width. Stem width was used as a measurement of flexibility based on the assumption that thin stems are more flexible and less resistant to breakage during machine harvest. Stem width was measured at the base of the main stem (Ft. Hancock-2001 and Hobbs) and below the main fork as well (Las Cruces and Garfield). Measurements were taken with a caliper.

Fork angle. The angle between the branches of the main fork was measured in degrees using a protractor. When more than two branches were present at the main fork, each angle was measured to determine the average.

Plant height. Plant height was measured in inches from the ground to the highest point of the plant as it stood naturally.

Height to main fork. Fork height was measured in inches from the ground to the first split in the main stem (main fork). This position is the first potential fruiting site. At Garfield,

the measurement was made to the height of the first fruit set rather than the fork, but the measurements are similar and, therefore, both are used to describe how the lowest setting fruit is affected by plant density.

Results

Thinning treatment

Different final plant densities may be difficult to achieve through the manipulation of hand thinning techniques that remove plants (table 2). Where plot size was very large (Ft. Hancock-2001-‘B-18’, Ft. Hancock-2002-‘B-18’, Las Cruces-2002-‘B-18’ and Las Cruces-2002-‘Sonora’), reducing thinning to 4 inches from 8 inches did not produce statistically different plant densities with the exception of the Ft. Hancock-2002-‘B-18’ study. Even where the plot size was much smaller (Hobbs-2002-‘B-58’ and Garfield-2003-‘B-58’), plant density was statistically the same at the 4-inch and 8-inch spacing in the Hobbs study. At Garfield, however, a different density was achieved at each spacing (2-inch, 4-inch, 8-inch). In all studies, the final density achieved with the no-thin treatment was substantially higher than the thinned densities.

The densities achieved under the no-thin treatment ranged from about 62,725 plants/acre (Ft. Hancock-2001-‘B-18’) to nearly 198,300 plants/acre (Ft. Hancock-2002-‘B-18’). These two years demonstrate how environmental factors can influence the final density of a no-thin field. Curly top, a viral infection, is highly destructive to chile seedlings and can cause high rates of mortality. In 2001, curly top was a widespread problem in the Southwest, and the field in Ft. Hancock was severely affected. By comparison, very little curly top showed up in chile fields in 2002, and the stand at Ft. Hancock was much thicker. Therefore, even at the same location with the same variety, seeder and seeding rate, the final density of a no-thin field is highly dependent on biotic and abiotic mortality pressures and may vary greatly year-to-year.

Yield per acre described by thinning treatment

Reduced thinning resulted in a yield/acre increase in only one of the six studies (table 3). Higher yields were obtained at spacings of less than 8 inches only in the Garfield 2003 study. At this location, the yield/acre was statistically the same for the no-thin, 2-inch and 4-inch plant spacings, all of which out yielded the 8-inch plant spacing.

For the majority of the study, higher yields were not obtained when thinning was reduced from the standard 8-inch spacing. At Ft. Hancock-2002-‘B-18’ and Las Cruces-2002-‘B-18’, the yield/acre was statistically the same at the 4-inch and 8-inch plant spacings, and the no-thin treatment caused a reduction in yield/acre. The yield/acre was statistically the same at the no-thin, 4-inch and 8-inch plant spacings in the other three studies: Ft. Hancock-2001-‘B-18’, Las Cruces-2002-‘Sonora’ and Hobbs-2002-‘B-58’.

ASTA described by thinning treatment

Thinning treatment had a significant effect on the level of extractable color in two of the six studies (table 4). As plant density increased with reduced thinning, a significant decrease in ASTA occurred in those two studies, and tended to decrease in the other four studies.

Table 3. Effect of thinning on dry yield/acre of paprika

Location, year variety	Thinning treatment (inches)				Overall treatment effect ^a
	8	4	2 ^b	No-thin	p-value
Ft. Hancock, 2001 'B-18'	2,713	3,816	-	4,217	0.6404
Ft. Hancock, 2002 'B-18'	2,665 <i>a</i>	2,366 <i>a</i>	-	1,624 <i>b</i>	0.0007
Las Cruces, 2002 'B-18'	5,526 <i>a</i>	5,387 <i>a</i>	-	4,568 <i>b</i>	0.0095
Las Cruces, 2002 'Sonora'	4,652	4,873	-	4,473	0.3032
Hobbs, 2002 'B-58'	6,881	6,748	-	7,355	0.2358
Garfield, 2003 'B-58'	3,736 <i>b</i>	4,585 <i>a</i>	4,546 <i>a</i>	4,880 <i>a</i>	0.0241

^a Significance at $P \leq 0.05$ followed by mean separation of yield by LSD.

Numbers with the same letter within a location/year/variety are not different at the 5% level.

^b 2-inch spacing only included at Garfield.

Table 4. Effect of thinning on extractable color (ASTA) of paprika.

Location, year variety	Thinning treatment (inches)				Overall treatment effect ^a
	8	4	2 ^b	No-thin	p-value
Ft. Hancock, 2001 'B-18'	276	262	-	260	0.4217
Ft. Hancock, 2002 'B-18'	238	227	-	215	0.3719
Las Cruces, 2002 'B-18'	392 <i>a</i>	356 <i>b</i>	-	238 <i>b</i>	0.0072
Las Cruces, 2002 'Sonora'	376	393	-	348	0.2286
Hobbs, 2002 'B-58'	283 <i>a</i>	279 <i>a</i>	-	254 <i>b</i>	0.0108
Garfield, 2003 'B-58'	259	253	252	242	0.4472

^a Significance at $P \leq 0.05$ followed by mean separation of ASTA by LSD.

Numbers with the same letter within a location/year/variety are not different.

^b 2-inch spacing only included at Garfield.

Table 5. Effect of thinning on the mean angle of the main fork of paprika.

Location, year variety	Thinning treatment (inches)			No-thin	Overall treatment effect ^a
	8	4	2 ^b		
	Extractable color (ASTA)				p-value
Ft. Hancock, 2001 'B-18'	39.06	39.78	-	36.08	0.1965
Las Cruces, 2002 'B-18'	53.34 <i>a</i>	47.67 <i>b</i>	-	34.11 <i>c</i>	0.0007
Las Cruces, 2002 'Sonora'	46.67 <i>a</i>	44.92 <i>a</i>	-	38.67 <i>b</i>	0.0180
Garfield, 2003 'B-58'	46.42 <i>a</i>	43.22 <i>a</i>	44.92 <i>a</i>	37.42 <i>b</i>	0.012

^a Significance at $P \leq 0.05$ followed by mean separation of fork angle by LSD.

Numbers with the same letter within a location/year/variety are not different.

^b 2-inch spacing only included at Garfield.

At Hobbs-2002-'B-58', the ASTA level was statistically the same at the 4-inch and 8-inch plant spacings, but no-thin resulted in significant reduction in the ASTA level. At Las Cruces-2002-'B-18', ASTA was statistically highest at the 8-inch plant spacing. No-thin and 4-inch spacings caused a significant decrease in ASTA from the 8-inch spacing. No statistical differences in ASTA were detected at the other four sites/years, regardless of final density. For all locations, ASTA values were greater than 215, well above the 200 level where processors begin paying premiums.

Plant architecture described by thinning treatment

Fork angle. Thinning treatment had a significant effect on the angle of the main fork at three of four locations where it was measured (table 5). As plant density increased with reduced thinning, the angle of the main fork decreased.

The effect of density on fork angle was most pronounced in the Las Cruces-2002-'B-18' study. The fork angle was statistically different at each treatment (no-thin, 4-inch, 8-inch), although the densities at the 4-inch and 8-inch plant spacings were statistically the same. Conversely, in the Garfield-2003-'B-58' study, where each treatment resulted in a different density, fork angle was reduced at the no-thin treatment only. Among the thinned treatments (2-inch, 4-inch, 8-inch), the fork angle was not affected. No-thin decreased the fork angle in the Las Cruces-2002-'Sonora' as well and, as with density, no statistical difference in fork angle between the 4-inch and 8-inch plant spacings was observed. At Ft. Hancock-2001-'B-18', thinning treatment did not significantly affect fork angle.

Although the results from these four studies are slightly varied, the inverse relationship between density and fork angle occurred in most. Whether a decrease in angle of a few degrees has an impact on machine harvest efficiency requires further investigation.

Stem thickness. Thinning treatment had a significant effect on stem diameter at the main stem's base in three of the five studies in which it was measured (table 6). Stem diameter below

Table 6. Effect of thinning on stem diameter of paprika.

Location, year variety	Thinning treatment (inches)								Overall treatment effect ^a	
	8	4	2 ^b	No-thin	8	4	2b	No-thin	p-value	
	Stem diameter above soil line (mm)				Stem diameter below main fork (mm)				above soil	below fork
Ft. Hancock, 2001 'B-18' ^d	13.43	14.56	-	12.43	-	-	-	-	0.3869	-
Las Cruces, 2002 'B-18'	15.28 <i>a</i>	13.39 <i>a</i>	-	10.38 <i>b</i>	15.13 <i>a</i>	12.82 <i>ab</i>	-	11.08 <i>b</i>	0.0257	0.0320
Las Cruces, 2002 'Sonora'	12.93	12.08	-	10.16	12.64	12.51	-	10.09	0.0671	0.0967
Hobbs, 2002 'B-58' ^d	15.83 <i>a</i>	15.88 <i>a</i>	-	10.94 <i>b</i>	-	-	-	-	0.0051	-
Garfield, 2003 'B-58'	11.86 <i>a</i>	9.89 <i>b</i>	10.27 <i>ab</i>	8.17 <i>c</i>	12.15 <i>a</i>	11.18 <i>ab</i>	10.75 <i>b</i>	9.08 <i>c</i>	0.0040	0.0013

^a Significance at $P \leq 0.05$ followed by mean separation of stem diameter by LSD.

Numbers with the same letter within a location/year/variety are not different.

^b 2-inches spacing only included at Garfield.

^c Stem diameter below the fork was not measured at Ft. Hancock, 2001, and Hobbs, 2002.

Table 7. Effect of thinning on height to either first fruit or main fork of paprika

Location, year variety	Thinning treatment (inches)				Overall treatment effect ^a
	8	4	2 ^b	No-thin	
	Height (inches)				p-value
Ft. Hancock, 2001 'B-18' ^c	10.03 <i>b</i>	9.69 <i>b</i>	-	11.93 <i>a</i>	0.0510
Hobbs, 2002 'B-58' ^c	8.03 <i>b</i>	10.83 <i>b</i>	-	14.94 <i>a</i>	0.0193
Garfield, 2003 'B-58' ^d	6.63 <i>c</i>	7.38 <i>bc</i>	7.97 <i>b</i>	9.87 <i>a</i>	0.0007

^a Significance at $P \leq 0.05$ followed by mean separation of height by LSD.

Numbers with the same letter within a location/year/variety are not different.

^b 2-inch spacing only included at Garfield.

^c Measurement made to height of main fork.

^d Measurement made to height of first fruit.

Table 8. Effect of thinning on plant height of paprika

Location, year variety	Thinning treatment (inches)			No-thin	Overall treatment effect ^a
	8	4	2 ^b		
	Height (inches)				p-value
Ft. Hancock, 2001 'B-18'	27.31 <i>b</i>	32.43 <i>ab</i>	-	36.82 <i>a</i>	0.0143
Las Cruces, 2002 'B-18'	32.5 <i>c</i>	34.76 <i>b</i>	-	36.93 <i>a</i>	0.0022
Las Cruces, 2002 'Sonora'	29.39 <i>b</i>	31.12 <i>b</i>	-	33.44 <i>a</i>	0.0122
Hobbs, 2002 'B-58'	19.83 <i>b</i>	23.17 <i>b</i>	-	33.17 <i>a</i>	0.0048
Garfield, 2003 'B-58'	21.44 <i>b</i>	21.44 <i>b</i>	23.54 <i>ab</i>	26.56 <i>a</i>	0.0193

^a Significance at $P \leq 0.05$ followed by mean separation of height by LSD.

Numbers with the same letter within a location/year/variety are not different.

^b 2-inch spacing only included at Garfield.

the main fork also was reduced significantly in two of the three studies. At both the soil line and below the main fork, no-thin caused the most significant decrease.

Stem diameter: Plant base. At Las Cruces-2002-'B-18' and Hobbs-2002-'B-58', the effect was significant at no-thin, while no difference was detected at the 4-inch and 8-inch plant spacings in either study. In the Garfield-2003-'B-58' study, stem diameter was thinnest at no-thin. At the 4-inch plant spacings, stem diameter was also thinner than at the 8-inch plant spacing, while stem diameter at the 2-inch spacing overlapped with both the 4-inch and 8-inch plant spacing. At Ft. Hancock-2001-'B-18' and Las Cruces-2002-'Sonora', thinning treatment did not show an effect on stem diameter at the plant base.

Stem diameter: Below main fork. At Las Cruces-2002-'B-18' and Garfield-2003-'B-58', stem diameter at no-thin was significantly smaller than at the 8-inch spacing. In the Garfield study, stem diameter also was reduced at the 2-inch spacing compared to the 8-inch, while at the 4-inch spacing, stem thickness overlapped with the 2-inch and the 8-inch spacings. In Las Cruces (2002-B-18'), the stem diameter at the 4-inch spacing overlapped with no-thin and 8-inch spacings. In the Las Cruces-2002-'Sonora' trial, thinning treatment did not influence stem diameter below the main fork.

Height of main fork or first fruit. Thinning treatment had a significant effect on main fork height in both studies in which it was measured and on height to the first fruit in the one study in which it was recorded (table 7). As plant density increased with reduced thinning, the height to the first fruiting position/fruit increased.

At Ft. Hancock-2001-'B-18' and Hobbs-2002-'B-58', the effect was significant at no-thin, while no difference was detected at the 4-inch and 8-inch plant spacings in either study. In the Garfield-2003-'B-58' study, the height to the first fruit was greatest under no-thin. At the 2-inch spacing, fruit height also was greater than at the 8-inch spacing, while fruit height at the 4-inch spacing overlapped with both the 2-inch and 8-inch plant spacings.

Overall, an increase in at least 2 inches was observed between the standard spacing and no-thin. This may be a significant amount, allowing the harvesting unit to fit below the lowest setting fruit.

Plant height. Thinning treatment significantly influenced plant height in all five of the studies in which plant height was measured (table 8). As plant density increased with reduced thinning, plant height increased.

Plant height was greater under the no-thin treatment in all the studies. At Las Cruces-2002-‘Sonora’ and Hobbs-2002-‘B-58’, plant height was not affected at the 4-inch and 8-inch spacings. While the densities achieved at the 4-inch and 8-inch spacings were the same in the Las Cruces-2002-‘B-18’ study, plant heights did separate at these two levels of thinning. Plant height was greater at the 4-inch plant spacing than at the 8-inch. In the Ft. Hancock-2001-‘B-18’ and Garfield-2003-‘B-58’ studies, plant height increased at no-thin compared to the 8-inch spacing, but was not different from the thinning treatment immediately above no-thin (4 inches in the Ft. Hancock-2002-‘B-18’ study and 2 inches in the Garfield-2003-‘B-58’ study).

Conclusions

Thinning created a significant effect on the yield, extractable color and growth habit of several paprika varieties. Distinct differences appeared more often between the no-thin and thinned treatments than among the thinned treatments alone. While no-thin had a positive effect on certain structural characteristics that may improve machine harvest efficiency such as narrowing the main fork angle, decreasing stem width and increasing plant and first fruit set heights, an increase in yield seldom occurred. In two of the studies, the no-thin treatment actually reduced yields. This suggests that these varieties already are near the plateau of peak yield when cultivated at a 3-plants-per-foot density.

Nevertheless, a shift in current thinning practices still holds merit. Denser populations will help ensure a more uniform stand that can better withstand environmental attacks such as curly top and harsh winds. Also, a thicker stand provides a constant stream of material for the machine harvester. Large gaps in the field often disrupt the flow of harvested material and reduce efficiency.

At this time, we recommend increasing plant populations on red chile and paprika that will be machine harvested to no less than an evenly distributed 40,000 plants per acre (3 plants per foot). The results of these studies suggest that plant density near 80,000 plants per acre can be tolerated. Plant density less than 20,000 plants per acre would hinder efficient machine harvesting.

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New Mexico Chile Task Force Publication List

Report 1: An Industry-University Response to Global Competition

Report 2: Chile Seed Germination as Affected by Temperature and Salinity

Report 3: Yield and Quality of Machine-Harvested Red Chile Peppers

Report 4: Chile Seed Quality

Report 5: Guidelines for Chile Seed Crop Production

Report 6: Improving Chile Harvesting and Cleaning Technologies

Report 7: Farm Labor Employers' Handbook

Report 8: New Mexico's Chile Pepper Industry: Chile Types and Product Sourcing

Report 9: Economic Impact of Southern New Mexico Vegetable Production and Processing

Report 10: Chile Pepper Growers' Notes: 2003

Report 11: Developing New Marketing Strategies for the Southwestern Chile Industry

Report 12: Incidence of the Beet Leafhopper, *Circulifer tenellus* (Homoptera:Cicadellidae), in New Mexico Chile

Report 13: Plant Spacing/Plant Population for Machine Harvest



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