Spring Freeze Damage to the 1996 Peach and Nectarine Crop in the Southeastern United States

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SUMMARY. This paper describes the climatic and cropping conditions in the major peach [*Prunus persica* (L.) Batsch] producing areas in the southeastern United States in 1996. The peach and nectarine crop was the smallest since 1955 due to a series of unusually cold temperatures in February, March, and April. Crop set was not strictly a function of late blooming. No variety produced a full crop across the region. Many reputedly hardy peaches cropped poorly. The only peach or nectarine varieties that produced substantial crops in multiple locations were 'La Premiere', 'Ruston Red', and 'Contender'. Cropping ability of some breeding selections shows that peach frost tolerance may be improved further.

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The southeastern United States is a major peach production area, usually accounting for about one-fourth of the U.S. fresh-market crop. The few nectarines grown are mostly sold locally. Although total regional crop losses are rare, the industry has concentrated in those locations with the best cropping records such as central Georgia and the Ridge area of South Carolina. In contrast to more northern states, mid-winter bud hardiness is of less concern than spring bud and flower hardiness. Research from Washington suggests that critical temperatures of 15 °F (−9 °C) are needed to kill 90% of flowers at first pink stage, whereas 24 °F (−4 °C) can kill 90% of blossoms at full bloom (Ballard et al., 1984). Temperatures in this range commonly occur in the southeastern United States during the spring. One strategy to avoid crop loss from spring frosts is to grow varieties requiring more cold before breaking dormancy, resulting in later bloom. However, winter chilling in the southeastern United States varies widely from year to year. Annual chilling [hours at <45 °F (7 °C)] at Byron, Ga., from 1 Oct. through 15 Feb. has ranged from 652 to 1608 in the last 60 years. In the warmer areas of the southeastern United States, the highest-chilling varieties suffer from inadequate chilling in low-chill years, resulting in erratic bloom and poor set. In addition, high-chilling varieties that crop in warmer areas often have a less round shape and retain an unattractive greenish ground color as they ripen. In practice, the range of suitable varieties for a given area may be quite limited.

Older peach growers remember 1955 as the last time most of the crop in the southeastern United States was lost. In that year a high-chilling winter was followed by warm weather in late February and early March, which resulted in an early bloom. At Fort Valley, Ga., in the main peach production area, most commercial varieties were in full bloom by 7 Mar. After a warm March, temperatures dropped to 26 °F (−3 °C) and 19 °F (−7 °C) on the nights of 26 and 27 Mar., respectively, killing the small fruit. According to local legend, only one peach was picked that year in the entire state of Georgia.

Notes from Hugh N. Starnes, a Univ. of Georgia horticulturist, recount a similar event in 1894 (Starnes, 1894). After a mild winter and a very

early spring budbreak, temperatures on 26 and 27 Mar. dropped to 21 °F (−6 °C) and 19 °F respectively, killing the small fruit and even damaging the wood on younger trees. Starnes also mentions an undocumented catastrophic spring freeze that occurred 16 to 20 Apr. 1849.

This paper documents the weather conditions and cropping records for the major peach production areas in the southeastern United States for 1996. Overall, the crop was the smallest since 1955, due to a series of severe freezes that occurred in February, March, and April. Adjacent states such as Arkansas and Texas also had near total losses due to freezes, except for some areas of southern Texas such as Weslaco. In other areas of Texas, the latest-blooming varieties that might have escaped the freeze damage suffered from insufficient chilling and also did not set a crop (D. Byrne, personal communication).

Calhoun, La.

Temperatures in November and December were near normal, while mean daily highs in January and February were 2 °F (1 °C) higher than normal. The severe early February freeze had little effect on flower buds since the previous temperatures were cold enough (mean temperature for week before was ≈45 °F) to maintain hardiness. When commercial varieties bloomed in early March, most had enough flowers for a full crop. Varieties up to 750 chill hours were in full bloom by 7 Mar. after 2 weeks of warm weather. The average high from 20 Feb. to 7 Mar. was 71.2 °F (21.8 °C), with five daily highs above 80 °F (27 °C). A high of 84 °F (29 °C) on 6 Mar. was followed by a low of 24 °F on 8 Mar. (Table 1). Mean high temperatures during 14 to 19 Mar. averaged 73.3 °F (22.9 °C), forcing most of the remaining varieties into bloom. Most of these flowers were killed by a low of 22 °F (−6 °C) on 20 Mar. Remaining live blooms on high-chill varieties such as 'Redhaven' and 'Newhaven' did not set, probably due to freeze damage to the stigma, which prevented fertilization. The only varieties that had a commercial crop were 'LaPremiere' and 'Ruston Red' (Table 2).

Clanton, Ala.

Commercial production in Alabama is heavily concentrated in the

central part of the state, mainly in Chilton and Autauga counties. About 10% to 25% of the crop is produced across portions of southern and northern Alabama. Cropping in Alabama was very light and officially estimated at 5% of normal. Weather data (Table 1) is from the research station at Thorsby in Chilton County. Each one of the freeze events resulted in severe damage to one or more varieties. Only through the use of some freeze protection were growers able to salvage even a 5% crop. Only 'LaPremiere', 'Ruston Red', and 'Contender' were able to withstand all the freezes. 'Norman' and 'Jayhaven', as well as a few others such as 'Harvester' and 'Redhaven', produced light crops. The specific site involved made a considerable difference in the fruiting of a variety.

Byron, Ga.

In 1995 at Byron, November and December were slightly colder than normal [mean monthly temperatures 4.5 °F (2.5 °C) and 1.5 °F (0.8 °C) below average, respectively]. In January, mean daily highs were only 1 °F

(0.5 °C) higher than normal, while February temperatures were normal. Chilling-hour accumulation was 1056 at the end of January, 134 h above normal, which increased the likelihood of an early bloom. A severe early February freeze (Table 1) killed flower buds of many commercial peaches, which had apparently dehardened. Flower bud survival in one block was 36% for 'Harvester,' 19% for 'Juneprince,' and 3% for 'Redglobe,' not what would be expected based on amount of bud development, since 'Redglobe' normally blooms later than the others. Surprisingly, many low-chill (400 to 600 h) peaches produced a substantial bloom at Byron in late February as the weather was unseasonably warm (but not as warm as in Calhoun). One explanation for their superior bud survival is that the lack of a crop the previous year resulted in a higher bud set and more carbohydrate reserves (Crane, 1930). When bloom of commercial varieties occurred in early March, many trees already lacked sufficient flowers for a full crop, and many of the surviving flowers were

deformed or incomplete. Most varieties in the 650- to 750-h range were in or past full bloom on 7 Mar., but nearly all were rated as having none to a few flowers per twig. Some higher-chilling varieties were badly damaged, while others had adequate developing flowers. Two subsequent freezes in March (Table 1) reduced the crop further. The first low of 18 °F (-8 °C) killed all flowers that had opened to that point, causing the orchards to look burned. Warm temperatures the next week forced out the remaining live flower buds, most of which were killed in late March. Many of the visually normal blooms that survived eventually dehisced and did not develop into fruit.

Despite the severe weather, a few varieties cropped well at the Southeastern Fruit and Tree Nut Research Laboratory at Byron, which is in the heart of the commercial production area. Although Table 2 results are from research plots, local commercial growers reported similar results with the more limited range of varieties that they grow. In northern Georgia, where

Table 1. Accumulated chill hours [<45 °F (7 °C) from 1 Oct. 1995] and significant freezes occurring in Spring 1996 in the southeastern United States (data from local experiment stations and National Weather Service). Because lows are reported for a 24-h cycle, which is usually offset from clock time, dates may be off by one. Chill hours are actual recorded hours for Calhoun and Byron. Other chill hours are calculated from maximum-minimum data.

Date	Parameter	Location									
		Calhoun La.	Thorsby Ala.	Tifton Ga.	Byron Ga.	Orangeburg S.C.	Pontiac S.C.	Johnston S.C.	Clemson S.C.	Spartanburg S.C.	Jackson Springs N.C.
3 Feb.	Chill	1015	1250	912	1103	1300	1424	1568	1363	1568	1596
3 Feb.	Low	14	13	36	29	28	27	27	24	28	20
4 Feb.	Low	9	7	18	14	20	18	22	12	17	12
5 Feb.	Low	11	6	13	8	14	9	10	9	6	3
6 Feb.	Low	16	7	12	8	19	10	10	17	14	4
7 Feb.	Low	36	27	21	20	25	19	20	NA ^a	22	18
8 Feb.	Low	47	34	25	27	35	19	25	NA	35	23
17 Feb.	Chill	1159	1444	1096	1293	1449	1678	1824	1565	1826	1836
17 Feb.	Low	19	19	25	22	22	21	21	22	22	19
18 Feb.	Low	28	28	25	24	27	22	25	27	21	26
8 Mar.	Chill	1271	1647	1176	1406	1480	1743	1902	1756	1874	2004
8 Mar.	Low	24	23	29	25	28	28	27	18	23	26
9 Mar.	Low	15	17	21	18	20	16	15	14	15	15
10 Mar.	Low	20	19	20	19	27	18	15	22	21	18
11 Mar.	Low	22	30	29	29	32	19	18	28	28	23
12 Mar.	Low	28	33	32	28	32	29	28	27	22	26
13 Mar.	Low	36	36	33	30	30	31	28	28	21	29
20 Mar.	Chill	NA	1752	1293	1526	NA	NA	NA	1881	NA	2140
20 Mar.	Low	22	33	37	33	34	35	32	34	35	35
21 Mar.	Low	29	31	37	33	28	30	30	29	29	29
22 Mar.	Low	29	30	36	28	29	27	27	27	25	26
23 Mar.	Low	35	33	35	31	28	27	28	30	26	29

^aNA = not available.

annual production is less reliable, the crop was extremely light. Overall, state production was estimated at 5% of normal.

The only varieties or advanced selections to crop near normally were 'LaPremiere', 'Harcrest', and BY81P1216. Nearly full crops were on

'Legend', 'Compact Elberta', 'Summer Pearl', 'Ruston Red', and 'Bobeva'. Unfortunately, none of these was being grown commercially in the area.

Table 2. Effects of spring freezes on the 1996 crop of peach and nectarine (nect) varieties in the southeastern United States. Cropping code: 0 = none; 1 = light, <5% of commercial crop; 2 = 5% to 25%; 3 = 26% to 50%; 4 = 51% to 75%; 5 = 75% to 100%; 6 = 100% or needing thinning.

Variety	Chilling requirement	Location (crop rating)									
		Calhoun La.	Thorsby Ala.	Attapulgus Ga.	Byron Ga.	Coastal Plain S.C.	Sandhills S.C.	Ridge S.C.	Clemson S.C.	Piedmont S.C.	Jackson Springs N.C.
Babygold's	850	---	---	---	0	0	0	0	2	2	---
Biscoe	900	---	---	---	3	---	---	2	2	---	0
Blake	750	---	1	---	1	1	---	0-4	1-2	2-5	---
Bounty	800	0	0	---	---	---	---	2	---	---	---
BY81P1216	950	---	2	---	4	---	---	---	---	---	---
Cal Red	800	---	1	---	0	0	---	0-3	2	2	---
Canadian											
Harmony	750	---	2	---	---	---	0	---	4	---	---
Candor	950	---	---	---	---	---	0	0	2	---	---
Carogem	950	0	0	---	1	---	---	---	3	---	---
Carolina Belle	750	0	0	5	1	---	---	---	---	---	0
Cary Mac	750	0	0	---	0	2	0	0	2	0	---
Contender	1050	0	3	---	1	2	3-5	0-5	2-5	2-3	2
Coronet	750	---	0	---	0	0	0	0-2	0-2	0	---
Correll	850	---	---	---	---	---	---	---	3	---	---
Cresthaven	950	0	2	---	1	5	2-4	0-5	3	2	---
Derby	750	0	2	---	---	---	---	0	2	0-1	---
Dixiland	750	0	0	0	---	---	---	---	---	---	---
Dixired	950	---	0	---	1	0	---	2	2	---	---
Elberta	850	0	1	---	1	1-2	---	---	---	---	---
Empress	650	---	0	0-1	0	0-1	---	0	0	---	---
Encore	950	---	2	---	---	---	2	5	2-3	2-3	0
Fayette	850	0	0	---	1	0	---	0	2	---	---
Fireprince	750	0	1	---	0	---	---	2-3	2	---	---
Flameprince	850	0	0	---	2	---	---	---	2	2	---
Flordaking	450	---	0	0	0	0	0	---	0	---	---
GaLa	750	0	0	0	1	---	---	---	---	---	0
Garnet Beauty	850	0	2	---	---	---	---	0-5	3	2	---
Georgia Belle	850	---	2-3	---	3	1-2	2	0	2	2	---
Glohaven	850	0	1	---	---	---	---	---	2	1-2	---
Goldcrest	600	---	0	---	0	0	---	---	1	---	---
Goldprince	650	---	0	0	0	2	0	0-4	0-2	0	---
Harcrest	850	---	2	---	4	1-2	---	---	---	---	---
Harvester	750	0-1	2	---	1	2-3	2	0-3	2	0-2	---
Jayhaven	950	---	3	---	---	---	---	---	2-3	---	---
Jefferson	850	0	0	---	1	---	0	0-3	2	2-3	---
Jerseyqueen	850	0	1	---	---	1	0	0	1-2	0	---
Junegold	650	0	0	2	0	0	0	0-2	2	---	---
Juneprince	600	0	0	0	0	0-2	0	0-3	0-2	0	---
Karla Rose											
(Snow											
Queen nect)	650	---	0	1	0	---	---	---	---	---	---
LaJewel	850	1	1	2	---	---	---	---	---	---	---
LaPremiere	1050	6	4-5	---	4	---	---	---	---	5-6	---
Legend	850	0	3	---	2	---	---	---	2	2	0
Loring	800	0	0	---	0	1	0	0-4	0-2	0	---
Majestic	800	0-1	0	5	1	---	---	---	0	---	---
Marqueen	750	1	0	---	---	---	---	---	---	3	---

Other varieties of northern origin such as 'Cresthaven', 'Redhaven', 'Redglobe', and the Paul Friday (PF) series cropped poorly. Seedlings BY93P3427 (descended from crosses with Louisiana selections and Stoneyhard from Japan) and BY93P5030 (descended from GA107 natural and Agua 6-4 from Mexico) set heavy crops that needed thinning. A dozen other seed-

ling trees that produced full crops were mostly descended from crosses using natural (local feral selections), Mexican (highland), or Japanese parents with late blooming characteristics.

Attapulgus, Ga.

The peach industry in southern Georgia, concentrated in Brooks County, produces predominantly early

season varieties. Breeding and variety testing is conducted at Attapulgus. Weather data (Table 1) is reported from nearby Tifton. Excellent chilling occurred early in the winter, followed by a warming trend in January, with daytime highs reaching above 70 °F (21 °C). Buds developed rapidly on the low-chilling varieties and selections, such that most of the 'Flo-

Table 2. Continued.

Variety	Chilling requirement	Location (crop rating)									
		Calhoun La.	Thorsby Ala.	Attapulgus Ga.	Byron Ga.	Coastal Plain S.C.	Sandhills S.C.	Ridge S.C.	Clemson S.C.	Piedmont S.C.	Jackson Springs N.C.
Monroe	750	---	0	---	---	2	---	0-4	2-3	2-5	---
Nectar	1050	---	0	---	---	---	---	---	2	2	---
Newhaven	950	0	2	---	---	---	---	3	2	2	---
Norman	850	---	3	---	3	1-2	---	2	---	---	0
O'Henry	750	0	0	0	0	0-1	---	1-2	0-2	1-3	0
Ouachita Gold	700	0	1	---	0	1	3	---	2	3	---
Parade	800	0	0	---	0	1-2	1	0	1	1-4	---
PF12A	750	---	---	---	1	---	---	---	5	---	---
PF17	800	---	---	---	1	---	---	---	5	---	---
PF23	650	---	---	---	1	---	---	---	5	---	---
PF5B	750	---	---	---	0	---	---	---	5	---	---
Ranger	1000	0	2	---	---	---	---	---	2	---	---
Raritan Rose	1050	---	---	---	---	---	---	---	5	---	---
Redcap	750	0	---	---	0	---	---	---	---	---	---
Redglobe	850	0	0-1	---	1	1-2	2	0-5	1-2	3	---
Redgold nect	850	0	---	---	2	1	---	---	1	2-5	0
Redhaven	950	0-1	2-3	---	1	---	0	0-2	2-4	2	0
Redskin	750	1	1	4	0	---	2	5	2	---	---
Regal	700	0	---	---	0	---	---	---	---	---	---
Rio Oso Gem	850	0	2	---	0	1	---	---	2	3-5	---
Roseprincess nect	850	---	3	3	3	---	---	---	0	---	---
Rubired	950	---	---	---	---	---	---	---	0	1	---
Ruston Red	850	3-4	4-6	---	4	---	---	---	---	---	3
Ryan Sun	850	0	0	---	0	3	---	---	0	2	---
Scarletpearl	750	0	0	0	1	---	---	---	0	---	---
Sentinel	850	---	0	---	0	---	---	5	2	---	---
Sheperd's Beauty	650	---	---	---	---	---	---	---	---	---	---
Springcrest	650	0	0	0-1	0	0	1	0-4	0	---	---
Stark Saturn	850	---	---	---	2	---	---	---	---	---	---
Summer Beaut nect	800	---	2	---	0	---	---	---	---	4	---
Summergold	750	---	---	---	1	---	---	---	0	---	---
Summer Lady	?	---	---	---	---	---	---	---	---	3-4	---
Summerprince	850	0	0	5	1	2	---	2	4	3	---
Sunbrite	750	0	0	---	0	0	---	0-2	2	0	---
Sunprince	800	0	0	2	1	0	---	0-3	1-2	---	---
Surecrop	950	0-1	1	---	---	---	2	0-4	2	2	0
Sweethaven	850	---	1	---	---	1	---	---	---	1-3	---
Topaz	700	---	0	---	---	---	0	0	0-2	0	---
Tyler	950	---	0	---	0	5	---	2	---	2	---
Winblo	850	0	1	2	1	---	---	0-2	2	0	0

^aNot grown.

rdadawn' and 'Flordaking' buds were killed during the early February freeze. Surviving flowers on the low-chilling varieties bloomed in mid-February. Moderate chilling varieties were in full bloom in late February to early March. These were devastated by the 9 to 10 Mar. freeze. It was expected that the highest chilling varieties (750 to 850 h) at Attapulgus would produce at least a partial crop, but most also failed (Table 2). The following varieties or selections (listed in order of ripening) produced 50% or greater crop: BY87P285, AP93-13, 'Summerprince', 'Roseprincess', AP93-2, AP96-8, AP96-9, AP93-25, 'Carolina Belle', AP96-11, and 'Majestic'.

Clemson, S.C.

Peach production in South Carolina is concentrated in two main growing regions, the Piedmont and Ridge areas, and two lesser regions, the Sandhills and Coastal Plains. The Piedmont production area is north of Spartanburg, whereas the Ridge area runs from Edgefield east through Johnston to Batesburg. The Sandhills production area is centered near McBee, northeast of Pontiac and Columbia. Coastal Plains production is located primarily around Santee, east of Orangeburg and near Kline north of Allendale. Clemson Univ. peach research plantings are at the Musser Fruit Research Center ≈6 miles west of Clemson.

The chill hours accumulated from November to February were above normal (Table 1) for Winter 1995–96 in all production areas of South Carolina. The low temperatures on 5 and 6 Feb. significantly reduced potential crop loads on some commercial varieties at Clemson and in all production areas except the Coastal Plain, which sustained somewhat less winter bud kill. Bud mortality of major varieties was estimated by examining 10 shoots per tree of 3 to 6 trees per variety. At the Musser Fruit Farm, 'Coronet' (80% bud kill), 'O'Henry' (60%), and 'Redglobe' (75%) experienced high bud death. Others with less but still significant winter bud kill were 'Blake' (20%), 'Goldprince' (35%), 'Jefferson' (25%), 'Jerseyqueen' (20%), 'Juneprince' (25%), and 'Parade' (45%). One would expect earlier blooming varieties such as 'Goldprince' and 'Juneprince' to suffer more bud damage than later blooming ones such as 'Redglobe' and 'Jerseyqueen'.

Bloom on commercial varieties at Clemson began in early March, ≈1 week earlier than normal. When low temperatures in the teens occurred on 8 and 9 Mar. (Table 1), many varieties were in the first bloom stage and had 10% to 30% open flowers. This freeze damaged almost all of the flower petals and nectaries and most of the reproductive parts that had survived the freeze on 5 to 6 Feb. Many of the unopened flowers (e.g., popcorn stage) had either pistils or anthers killed. Moreover, due to the nectary and anther damage, bee activity was very low (i.e., little nectar or pollen) and many anther-damaged flowers did not appear to set. Similar flower conditions were reported across the state after this freeze.

Warm temperatures after the early March freeze forced the remaining basal shoot flowers to open, many of which were deformed or did not develop fully. Some varieties had flowers with no pistil and other varieties had flowers with no functional anthers. Most of these flowers abscised. Freezes on 21 to 23 Mar. (Table 1) further reduced the flowers that had survived the initial freezing events. All crop data listed in Table 2 for Clemson were from varieties not near wind machines, although some varieties that produced ≈25% of a crop were partially protected from the late March freezes because they were near wind machines. Due to these freezing events, South Carolina peach production in 1996 was only 10% to 15% of normal.

Jackson Springs, N.C.

Although substantial chilling occurred by early February in North Carolina (Table 1), trees were dormant for the February freezes. By early March, commercial trees were 30% to 50% in bloom. Most trees were in full bloom by the 20 Mar. freeze and suffered serious damage. The remaining fruit were mostly at shuck split when a final freeze occurred in April. The only commercial varieties that cropped at all at the Sandhills Research Station in Jackson Springs were 'Contender' and 'Clayton'. Advanced selection NCC5S-005, derived from the cross Contender x PI134401, had a 50% crop. This selection had a full, thinnable crop at a grower test site 5 miles from the Sandhills Station. Selections NCC5S-017 and NCC5S-020, both derived from a cross of Contender x Calanda de San

Miquel selection, had ≈20% of a crop. 'Calanda de San Miquel' is a high-chilling, feral Spanish peach population. Other selections that had 10% to 30% of a crop were second-generation descendants from crosses of 'Reliance' with various commercial varieties, especially 'Contender' and 'Encore'. 'Harrow Blood' and offspring derived from a cross of Harrow Blood x Rutgers Redleaf 2n had a heavy crop until it was eliminated by a final freeze of 28 °F (−2 °C) on 11 Apr. Overall, cropping in the North Carolina Sandhills region was very light.

Conclusions

Only general observations are possible due to the lack of uniform replicated plots across locations. Chilling requirement and origin did not seem to be reliable indicators of cropping ability, although most of the cropping that occurred was on higher-chill varieties. There are many factors that contribute to ability to crop (Scorza and Sherman 1996), such as previous crop, winter reserves, tree vigor, bud number (Okie and Werner, 1996), bud failure (Weinberger 1967), blind node formation (Boonprakob et al., 1996), winter bud hardiness, bud dehardening rate, developing-bud hardiness, bloom hardiness, and uniformity of bud development, and subsequent bloom. Depending on the environment in a particular spring, different factors may be important, resulting in variability from year to year and orchard to orchard. Spring 1996 was unusual in that there were four or five important low-temperature events, resulting cumulatively in a very severe test of cropping ability. It was apparent at several locations that cold damage was not strictly related to degree of flower bud development. Contrary to conventional wisdom, buds just beginning to develop seemed in many cases more cold-tender than those nearer to showing pink.

There has been a trend in central Georgia and perhaps elsewhere to plant lower-chilling varieties than were grown in the past. In 1955, there were no 650-h peaches grown on a large scale. Lower-chilling peaches bloom earlier, allowing a longer growing season for a given harvest date, and so making it easier to obtain larger fruit size compared to a later blooming peach. As growers have shifted to supply the early season market, early

blooming has been an advantage. In addition, many of the breeding programs in northern states have been closed, so there are fewer new varieties developed with a higher chilling requirement or higher bud hardiness. Older varieties may be less competitive in terms of size, firmness, or attractiveness, so the newer lower-chill varieties have often been planted instead.

Those varieties cropped over several locales, such as 'LaPremiere' and 'Contender', are good candidates for growers to plant as insurance against similar losses. Some of these varieties are less competitive in normal or low-chill years, and a grower may want to plant other varieties as well in their season. The cropping ability of some breeding material suggests that crop tolerance to spring frosts may be improved further.

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Responses of Field-grown Tomatoes to Nitrogen Sources

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SUMMARY. Although the effect of various N fertilizers on tomato yield and quality has been previously examined, much of this research was conducted in hydroponic or greenhouse studies. The objective of this research was to examine the effect of N fertilizer sources (ammonium nitrate (NH_4NO_3), potassium nitrate (KNO_3), urea ($\text{CO}(\text{NH}_2)_2$), urea ammonium nitrate (UAN), and calcium nitrate ($\text{Ca}(\text{NO}_3)_2$) on tomato (*Lycopersicon esculentum* Mill.) growth, yield, and fruit quality. The 2-year experiment was conducted using black plastic mulch covered raised beds with drip fertigation. A total of 180 lb/acre ($202 \text{ kg}\cdot\text{ha}^{-1}$) N was applied with each N source, with 25% applied preplant and premulch and remaining N applied as 10 weekly applications of 13.5 lb/acre ($15.2 \text{ kg}\cdot\text{ha}^{-1}$). If an N source contained Ca or K, that amount was applied to all other N sources (preplant and fertigated) as potassium chloride (KCl) or calcium chloride (CaCl_2). Collected data included plant height, leaf N concentration, and yield. Different N sources had varying and inconsistent effects on fruit yield and quality. Although plant height and stem diameter from UAN treatments were always smaller than those from other N sources, this effect did not extrapolate to decreased total marketable yield. Differences in N concentration of tomato leaf tissue were not consistent with N source and were not related to differences in tomato yield. There were few differences in yield

and quality of nonmarketable fruit due to N source. In this one-site, 2-year study, it appears that any of the N sources studied would be suitable for tomato production, if price of N fertilizer materials are the same.

The effect of different nitrogen (N) sources on crop growth and production has long been a topic of interest among scientists. Reasons for selecting a certain N form may be environmental, such as using positively charged ammonium forms to reduce leaching losses; may be economic, when a cheaper form of N is selected; or may be quality and quantity issues, when one form of N produces a better crop than another form.

Often, the source of fertilizer N becomes a nitrate (NO_3^-) versus ammonium (NH_4^+) issue. In greenhouse hydroponic studies, turnip (*Brassica rapa* L.) and watermelon (*Citrullus lunatus* Thumb.) growth was adversely affected by nutrient solution ratios high in NH_4^+ (Simonne et al., 1992, 1993). In both cases, plants expressed symptoms of NH_3 toxicity when grown in nutrient solutions that contained high levels of NH_4^+ .

Tomatoes grown in nutrient solution culture exhibited reduced vegetative growth as the NH_4^+ content of the NO_3^- to NH_4^+ ratio increased above 25% (Hartman et al., 1986). When any part of the N was supplied by NH_4^+ , the number of fruit formed at each flower cluster was not affected, but fruit weight was reduced and incidence of blossom-end rot increased. In another study, tomatoes grown in $(\text{NH}_4)_2\text{SO}_4$ had lower shoot dry weights than tomatoes grown in urea or $\text{Ca}(\text{NO}_3)_2$ at 4 weeks growth in nutrient solution (Barker and Corey, 1990). When the same experiment was conducted in soil (soil series was not provided), dry weight of tomato shoots grown in $(\text{NH}_4)_2\text{SO}_4$ was less than those grown in $\text{Ca}(\text{NO}_3)_2$. Using nutrient film techniques, Qasem and Hill (1993) demonstrated that NO_3^- N was the best N source for tomato plant growth, as shoot fresh and dry weight of tomato was reduced when plants were grown with urea or NH_4^+ N as the N source.

In field studies, the impact of NH_4^+ N nutrition on vegetable crop growth and yield is less clear. When

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