Nitrogen Fertilizer Management Practices to Enhance Seed Production by ‘Anaheim Chili’ Peppers

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Abstract. The effects of six applied N treatments differing by rates and frequencies of application on the yield and quality of pepper (\textit{Capsicum annuum} var. \textit{annuum} L. ‘Anaheim Chili’) grown for seed was studied. The timing of N applications was based on crop phenology, leaf petiole nitrate-nitrogen concentrations (NO\textsubscript{3}-N) minimum thresholds, and \textit{in situ} measured N concentrations of fixed amounts of N. Solubilized NH\textsubscript{4}NO\textsubscript{3} was applied through a trickle-irrigation system to ensure uniform and timely applications of N. Rate of mature (green and red) fruit production was unaffected by any treatment except weekly applications of 28 kg·ha\textsuperscript{-1} of N, which stopped production of mature fruit before all other treatments. Early season floral bud and flower production increased with increasing amounts of N. The two highest total N treatments produced more floral buds and flowers late in the season than the other treatments. Total fruit production was maximized at 240 kg N/ha. Differences in total fruit production due to frequency of N application resulted at the highest total N level. Red fruit production tended to be maximized with total seasonal applied N levels of 240 kg·ha\textsuperscript{-1} and below, although weekly applications of N reduced total fruit production. Total seed yield was a function of red fruit production. Pure-live seed (PLS) production was a function of total seed production. Nitrogen use efficiency (NUE) for red fruit production also decreased with N rates >240 kg·ha\textsuperscript{-1}, but PLS yield and NUE decreased in a near-linear fashion as the amount of total seasonal applied N increased, regardless of application frequency. Season average NO\textsubscript{3}-N (AVE NO\textsubscript{3}-N) values >4500 mg·kg\textsuperscript{-1} had total seed and PLS yields less than those treatments <4000 mg·kg\textsuperscript{-1}. Six-day germination percentage was reduced with weekly N applications of 14 kg·ha\textsuperscript{-1}. Seed mass was reduced with weekly N applications of 28 kg·ha\textsuperscript{-1}. Final germination percent, seedling root length and weight, and field emergence were unaffected by any of the N treatments. These findings indicate that different N management strategies are needed to maximize seed yield compared to fruit yield and, therefore, there may be an advantage to growing ‘Anaheim Chili’ pepper specifically for seed.

Recommendations for N fertilization of peppers grown in California are 170–225 kg·ha\textsuperscript{-1} (Sims and Smith, 1984). ‘Anaheim Chili’ peppers respond to 224 and 336 kg·ha\textsuperscript{-1} depending on the amount of N already present in the soil (Ririe, 1977). Depending on specific location conditions, commercial producers of ‘Anaheim Chili’ peppers in California use between 56 and 336 kg·ha\textsuperscript{-1} (C. Mouwen, personal communication, 1989).

It is well-established that N influences the growth and development of pepper grown for fruit. This effect depends on the available N in the soil and on the amount of applied N (Cochran, 1936; Maynard et al., 1962; O’Sullivan, 1979; Panpruik et al., 1982; Piazza and Venturi, 1971; Relwani, 1963; Somos et al., 1976; Stroehlein and Oebker, 1979; Sundstrom et al., 1984). However, results are related to production region. Maximum fruit production has been achieved with applications as low as 70 kg·ha\textsuperscript{-1} (O’Sullivan, 1979) as to high as 224 kg·ha\textsuperscript{-1} (Locascio and Fiskell, 1977).

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Use of plant tissue N concentrations provides a means to evaluate the N nutrient status and effectiveness of applied N in relationship to that available in the soil. Several accounts relate plant tissue N concentration in pepper to plant growth, development, and fruit maturity. These reports are difficult to compare because different plant parts were sampled for total N or NO\textsubscript{3}-N analysis. Young leaves and leaf petioles tend to contain higher NO\textsubscript{3}-N than older leaves and other plant parts. Additionally, varying plant tissue NO\textsubscript{3}-N were obtained with similar amounts of applied N, indicating that different amounts of N were available to the crop from the soil N reserve in addition to the applied N. Also, geographical location appears to greatly influence the findings. Thus, Thomas and Heilman (1964) reported that, under greenhouse conditions, the critical total leaf N concentration (including NO\textsubscript{3}-N) was 40,000 mg·kg\textsuperscript{-1} Lorzen and Tyler (1983) in California specified deficient and sufficient leaf petiole NO\textsubscript{3}-N that relate to early growth (first bloom), early fruit set, and full fruit size. The recommended ranges were 5000–7000, 1000–1500, and 750–1000 mg·kg\textsuperscript{-1} respectively. Another report from California showed that 224 to 336 kg·ha\textsuperscript{-1} of applied N was required to meet these recommended leaf petiole NO\textsubscript{3}-N levels (Ririe, 1977). In Arizona, stem tissue NO\textsubscript{3}-N of 8000–10,000 mg·kg\textsuperscript{-1} at heavy fruit set were reported not sufficient to produce high yields of fruit. This level was achieved with a minimum of 100 kg applied N/ha. Nitrogen deficiency was noted when NO\textsubscript{3}-N fell below 2000 mg·kg\textsuperscript{-1} (Stroehlein and Oebker, 1979). Panpruik et al. (1982) indicated that leaf petiole NO\textsubscript{3}-N should be maintained at 4000 mg·kg\textsuperscript{-1} through...
mid-season to avoid fruit yield reductions in New Mexico. O’Sullivan (1979) in Ontario, Canada, showed that fruit yields were reduced when leaf petiole NO₃-N fell below 4000 mg·kg⁻¹. This level was achieved with 35 to 70 kg·ha⁻¹. Thomas and Heilman (1967) reported from Texas that total plant dry matter production was restricted below 40,000 mg·kg⁻¹ as a result of <134 kg·ha⁻¹ of N being applied before planting.

Little research has been done to determine the effects of N fertility on the yield and quality of pepper grown for seed. Gill et al. (1974) reported that an increase in applied N from 0 to 370 kg·ha⁻¹ did not produce a proportional increase in seed yield. Since the production of seed is not of concern when producing market fruit, it is important to understand the effects of N fertilization on pepper grown specifically for seed. Much of the ‘Anaheim Chili’ pepper seed produced is a bypass product from commercial food product processing (C. Mounen, personal communication). This study was undertaken to determine the effect of N treatments on the reproductive development and seed production of ‘Anaheim Chili’ peppers grown specifically for seed. The treatments used were based on crop phenology, leaf petiole NO₃-N minimum thresholds, or calendar schedule schedules of fixed N amounts.

Materials and Methods

Field experiment and analyses. The study was conducted on a Hanford sandy loam soil (coarse-loamy, mixed, thermic Typic Xerorthent) at California State Univ., Fresno. The experimental area had been uniformly cropped with carrot grown for seed the previous season. ‘Anaheim Chili’ pepper seeds were planted 16 May 1986 (day 136) in two rows 20 cm apart on preshaped 1-m-wide beds. Each plot consisted of four beds 14 m long. The experimental area was sprinkler-irrigated until seedling emergence. The plants were thinned to 25 cm within each planting row on 11 June (day 162). Irrigation water was then applied by a Netafim drip irrigation system (Fresno, Calif.) consisting of laterals placed on the center of each bed with in-line, turbulent-flow emitters spaced every 50 cm along the lateral, each discharging 2 liters·hr⁻¹. Water applied to each treatment was measured using 19-mm flow meters to ensure uniform water and fertilizer applications to the various treatments. Irrigation water was applied when tensiometer readings were between 0.030 and 0.035 mPa at 40-cm soil depth, about every 5 to 7 days, depending on the weather.

A blanket application of 30N–90P.O.–112K.O (kg·ha⁻¹) in a concentrated stock solution was made 13 June (day 164) through the trickle-irrigation system. Six applied N treatments in the form of NH₄NO₃, which differed by rates and frequencies of application, were replicated four times (Table 1). The treatments were based on crop phenology (70-3X = 70 kg·ha⁻¹ at establishment, early fruit set, and full fruit size); leaf petiole NO₃-N minimum thresholds (35-5K = 35 kg·ha⁻¹ whenever NO₃-N decreased to 5000 mg·kg⁻¹; 35-2K = 35 kg·ha⁻¹ whenever NO₃-N decreased to 2000 mg·kg⁻¹; and 70-5K = 70 kg·ha⁻¹ whenever NO₃-N decreased to 5000 mg·kg⁻¹); or fixed N rates applied on a calendar schedule (14-W = 14 kg·ha⁻¹·week⁻¹ and 28-W = 28 kg·ha⁻¹·week⁻¹). The total seasonal applied N for the six treatments was 240, 275, 310, 170, and 310 kg·ha⁻¹, respectively. Solubilized NH₄NO₃ was injected into the irrigation system through Venturi injectors to establish the variable N treatments. The amounts of total applied N corresponded with a range commonly used for ‘Anaheim Chili’ peppers grown in California.

Fifty leaf petioles from fully expanded young leaves (Lorenz and Tyler, 1983) were sampled at random between 1100 and 1300 hr from each plot about weekly from 8 July (day 189) to 27 Sept. (day 260) for NO₃-N determination. One-half gram of ground material was extracted with 50 ml of 0.1 M aluminum sulfate for 0.5 hr. Nitrate-N concentration was determined with an ion selective electrode.

About every 14 days beginning 14 July (day 195) and ending 3 Sept. (day 247), five plants were chosen at random, uprooted, and the number of flower buds, flowers (fully opened), and set fruit (both developing and mature) were counted for each experimental unit. At maturity (3 Oct., day 276), total fruit yield (red and green fruits, both full-sized) was obtained for a once-over harvest from 6 m of row from the two middle rows of each plot. Red fruits were separated from green and both were weighed. Seeds were extracted from the red fruits with a modified version of a mechanical fruit crusher (Wehner et al., 1983). The seeds were then washed with a seed cleaning sluice (Steiner and Letizia, 1986), separated into fractions that either sank or floated, and dried at 31°C to constant weight (≈ 10% moisture) in a forced-air seed drier. The seeds were then cleaned using a continuous flow aspirator and weighted to determine total seed yield and seed mass. Seed germination was determined according to AOSA rules (Association of Official Seed Analysts, 1978), with counts made on days 6 (early count germination) and 14 (final count germination). Pure-live seed was determined by multiplying seed yield by final count germination (Copeland and McDonald, 1985). Seedling root length and seedling dry weight were also determined. Three 100-seed replicates from each experimental unit were seeded 1 cm deep and 2 cm apart on 1-m-wide beds on 1 Apr. 1987 to determine field emergence. The area was sprinkler-irrigated daily to maintain uniform soil moisture. Final seedling emergence was determined when all emerged seedling had reached the first true leaf.

Total and red fruit, and total seed and PLS yield N use efficiency (NUE) were calculated as the yield of the respective components per amount of total N applied for each treatment.

| Table 1. Dates and amounts of six applied N treatments to ‘Anaheim Chili’ pepper grown for seed at Fresno, Calif., in 1986. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Day of year of application | Treatment | 70-3X | 35-5K | 35-2K | 70-5K | 28-W |
| (kg·ha⁻¹) | (kg·ha⁻¹) | (kg·ha⁻¹) | (kg·ha⁻¹) | (kg·ha⁻¹) | (kg·ha⁻¹) | (kg·ha⁻¹) |
| 164 | 184 | 191 | 198 | 205 | 212 | 219 | 226 | 233 | 241 | 247 | Total |
| 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 |

Results and Discussion

Reproductive development. Initial flower bud production (day 195) was relatively unaffected by the different treatments (Fig. 1a). The number of flower buds present at day 203 was positively related to the amount of total applied N to that time. This result agrees with the findings of Cochran (1936) and May-
nard et al. (1962) for a first set of fruit, although no effect was observed for the average over two harvests. Maximum flower bud and flower load (Fig. 1b) was reached by the time of maximum fruit set (day 231; Fig. 1c) for all treatments except 70-5K, which had achieved maximum load by early fruit set (day 217). Flower bud and flower production by day 247 were greater for treatments 28-W and 70-5K (both receiving the greatest amount of total applied N for all treatments, 310 kg·ha⁻¹, compared to all other treatments (Fig. 1a and b). Maximum new fruit set (buttons) was achieved by day 231 for all treatments, with the rate of new fruit production decreasing after this time (Fig. 1c). The number of fruit that had set (achieved a minimum length of 2 cm) continued to increase through day 247 for all treatments except 28-W, which reached maximum fruit production at day 217, the time of initial full fruit sizing (Fig. 1d). This was the only substantial modification in plant phenology caused by the different treatments. The weekly application of N at 28 kg·ha⁻¹ appeared to allow continual initiation of floral structures (Fig. 1a), but hindered further flowering (Fig. 1b) and fruit set (Fig. 1d). This finding has not been noted in other reports were high N levels were used, and maybe due to the high (weekly) frequency of application.

The relative equal time of initial bud formation and flowering for all treatments is in agreement with the findings of Thomas and Heilman (1967), but contrary to Gill et al. (1974), who found flowering to be delayed with increasing levels of applied N. The initial increase in number of flower buds and flowers with increasing amount of N also agrees with Cochran (1932) and Thomas and Heilman (1967).

At final harvest (day 276), 70-3X produced the greatest amount of total fruit (red and green) of all the treatments (Fig. 2).

Treatment 28-W was the lowest-yielding, with the remaining treatments being intermediate and roughly decreasing in order according to increasing frequency and amounts of applied N. Treatment 70-5K, which received the same total seasonal application of N as 28-W, yielded more total fruit. This result indicates that frequency of application affected plant performance and that total fruit yield is not a simple function of total applied N. The decrease in fruit yield with the higher levels of N is in agreement with the findings of Ahmed (1984), Piazza and Venturi (1971), Thomas and Heilman (1967), and Stroehlein and Oebker (1979). The absence of change in fruit yield, with differing levels of applied N below 210 kg·ha⁻¹, agrees with O’Sullivan (1979) and Panpruik et al. (1982).

Red fruit yield was the highest for 70-3X and 35-2K and the lowest for 28-W. Treatments 35-5K, 70-5K, and 14-W were intermediate in their responses (Fig. 2). A very weak negative relationship existed between red fruit yield and total applied N, with maximum red fruit production at 240 kg·ha⁻¹. Applications of N in excess of 240 kg·ha⁻¹ decreased red fruit production. When N at 170 kg·ha⁻¹ was applied in either weekly application (as in the 14-W treatment), or when petiole N levels were 2000 mg·kg⁻¹ (as in the 35-2K treatment), the effects on fruit production were different. Greater red and total fruit yields were realized when N was applied to maintain petiole NO₃⁻N levels >2000 mg·kg⁻¹.

Total and red fruit NUE decreased as the amount of applied N increased (Fig. 3a). Total applied N in excess of 240 kg·ha⁻¹ reduced NUE for both fruit classes. The effect of frequency of application on total and red fruit NUE was not as clearly defined as it was for the respective component fruit production.

Seed quality. Six-day germination percent, which is a mea-

Fig. 1. Effect of six applied N treatments on flower bud, flower, immature, and mature fruit development of ‘Anaheim Chili’ pepper grown for seed. Treatments: 70-3X = 70 kg N/ha at establishment, early fruit set, and full fruit size; 35-5K = 35 kg N/ha whenever petiole NO₃⁻N content decreased to 5000 mg·kg⁻¹; 35-2K = 35 kg N/ha whenever petiole NO₃⁻N content decreased to 2000 mg·kg⁻¹; 70-5K = 70 kg N/ha whenever petiole NO₃⁻N content decreased to 5000 mg·kg⁻¹; 14-W = 14 kg N/ha each week; 28-W = 28 kg N/ha each week.

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sure of seedling vigor, was greatest for 70-5K and 35-2K but least for 14-W (Table 2). The other three treatments were intermediate in their early germination response. The frequency of application for the two highest total seasonal applied N treatments (28-W and 70-5K) did not affect early count germination percentages (Table 2). However, seedling dry weight, root length, and field emergence, which also are indicators of seed vigor, were not affected by the different N treatments. The absence of a relationship between 6-day germination percent and these other indicators of vigor suggests that N fertility has little if any affect on seed vigor. Final germination percent (14-day) was not affected by any of the applied N treatments.

Seed mass was related more to PLS yield \( R^2 = 0.864 \) than total seed yield \( R^2 = 0.779 \) (Fig. 4). The 28-W treatment produced the lightest seeds and had the lowest PLS yield of all treatments. This relationship indicates that plant N status affects both seed yield (see Fig. 6 a and b) and individual seed mass (Fig. 4). Since red fruit production was also greatly reduced in this treatment (Fig. 2), it appears that the weekly applications of N at 28 kg·ha\(^{-1}\) were detrimental to 'Anaheim Chili' pepper reproductive development.

**Seed yield components and seed yield relationships.** Production of red fruit (which produce viable seeds) was a linear function of total fruit yield (Fig. 5a). However, both total and PLS yields were nonlinear functions of red fruit yield and were maximized at a yield of \( \approx 8 \) t·ha\(^{-1}\) or higher (Fig. 5b). Thus, maximum seed yields are not equated with maximum red fruit production. Since final count seed germination percent was not affected by any of the treatments, PLS production was a linear function of total seed production \( r^2 = 0.977; P = 0.004 \). Therefore, maximum PLS yield was obtained by maximizing total seed production.

Total and PLS yields were functions of total applied N (Fig. 6a). Applied N rates >240 kg·ha\(^{-1}\) resulted in decreased seed yields. Treatments 35-2K, 14-W, and 70-3X produced the greatest amounts of total and pure-live seed, 28-W produced the least, and 35-5K and 70-5K were intermediate in their responses. Frequency of application was important only at the
high total N level, indicated by the lower total and PLS seed yield for treatment 28-W compared with 70-5K (Fig. 6a). Total seed and PLS yields were more closely related to total applied N ($R^2 = 0.893$ and 0.851, respectively) than total and red fruit yields ($R^2 = 0.393$ and 0.658, respectively). Both total seed and pure-live seed NUE decreased in a near linear fashion as total applied N increased and were not influenced by frequency of application (Fig. 3b). This result differs from the response for total and red fruit NUE, which did not decrease until >240 kg N/ha was applied and was affected by frequency of application (Fig. 3a). The absence of a positive relationship between seed yield and N is contrary to the findings of Gill et al. (1974).

Leaf petiole N0-N and its relationship with reproductive development and fruit and seed yield. Leaf petiole N0-N generally increased rapidly within 1 week of application of N at 35 kg·ha$^{-1}$ or more and then decreased the following week (Fig. 7). Weekly applications of 14 kg·ha$^{-1}$ maintained a relatively constant leaf petiole N0-N status <2000 mg·kg$^{-1}$, indicating a possible maintenance level of N required by the crop throughout the growing season. Weekly applications of 28 kg·ha$^{-1}$ resulted in a gradual, steady increase in leaf petiole N0-N through the season.

Each single application of 70 kg·ha$^{-1}$ was adequate to raise the petiole N0-N above 5000 mg·kg$^{-1}$ (treatments 70-3X and 70-5K). For three cycles of application, two consecutive weekly applications of 35 kg·ha$^{-1}$ (treatment 35-5K) were needed to raise the petiole N0-N to the 5000 mg·kg$^{-1}$ level. Single applications of this same amount (treatment 35-2K) were not sufficient to reach the 5000 mg·kg$^{-1}$ level at any time during the experiment, except for the N application during early plant establishment (day 184).

Previous research has reported critical plant tissue N0-N levels of at least 4000 mg·kg$^{-1}$ to be necessary to maintain fruit yields (O’Sullivan, 1979; Panpruik et al., 1982). In this study, AVE N0-N >4000 mg·kg$^{-1}$ were obtained with treatments 28-W, 70-5K, 70-3X, and 35-5K (Fig. 1). Treatments with AVE N0-N values >4500 mg·kg$^{-1}$ had total and pure-live seed yields lower than those treatments <4000 mg·kg$^{-1}$ (with the exception of 70-3X PLS, which was intermediate to the two groups) (Fig. 6b). Treatment 28-W, the most detrimental treatment in regards to both fruit and seed production, had the second-highest AVE N0-N of all treatments. Treatment 70-3X had the highest total fruit yield and along with treatment 35-2K the highest red fruit yields.

Overall, leaf petiole N0-N was unrelated to number of flower buds, flowers, button fruit, and total fruit on the plant at any time during the experiment and therefore was not suitable as a predictor of reproductive status (data not shown). There was also no relationship between AVE N0-N and total or red fruit yield (data not shown). Treatment 70-5K had the highest AVE N0-N and received the same total amount of N as 28-W, but had a higher total and PLS yields (Fig. 6b). This substantiates that frequency of N application affects pepper plant growth. Treatments 14-W and 35-2K had the highest seed yields with treatment 70-3X intermediate to the higher and lower seed-yielding groups (Fig. 2).

These findings indicate that total seed and PLS yield are affected by both total applied N and frequency of application.
Both total and red fruit production appear to be affected more by timing and frequency of N applications than by total seasonal applied N. Total fruit yield was maximized at 240 kg N/ha, while red fruit, total seed, and PLS yields decreased with increasing N. The greatest efficiency of seed production was obtained from 170 kg N/ha or with AVE NO\textsubscript{3}-N values <4000 mg·kg\textsuperscript{-1}. Different N management strategies should be considered to maximize seed yield and NUE compared to total fruit yield. Petiole NO\textsubscript{3}-N content can be used as an indicator of ‘Anaheim Chili’ pepper crop N status for seed production, but further research is needed to determine exact N fertility strategies needed for maximum seed production by this cultivar.

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