Nitrogen and Potassium Fertility Affects Jalapeño Pepper Plant Growth, Pod Yield, and Pungency

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Abstract. The influence of N and K rates in Hoagland's nutrient solution on Jalapeño pepper (*Capsicum annuum* L.) plant growth and pod production was determined on greenhouse-grown plants in sand culture. Varying the rates of N (1 to 30 mM) and K (1 to 12 mM) in Hoagland's solution identified optimum concentrations for Jalapeño plant growth and pod production. Two experiments were conducted to determine Jalapeño pepper sensitivity to differential fertilization. In the experiment seeded in April, nutrient treatments began at transplanting, and in the one seeded in May, treatments began after all plants had flower buds and half had flowered. Biomass and pod production per plant responded curvilinearly to N rate in both experiments. Optimum N rate for pod yield was 15 mM. Nitrogen rate affected pungency of pods only in the first experiment, with 1 mM N reducing capsaicin levels in fruit compared to other N rates. Biomass, fruit count, and fruit weight per plant increased linearly with increasing K rate in the first experiment and curvilinearly with K rate in the second experiment. The optimum K rate for pod yield was 6 mM. Potassium rates did not affect pod pungency. Jalapeño peppers grown in sand culture required 15 mM N and at least 3 mM K for optimum pod production.

The Jalapeño is one of the most popular hot (pungent) peppers used in cooking and in the international spice trade (Andrews, 1984; Bosland, 1992). The demand for hot peppers is increasing in the United States, as suggested by a recent report that salsa has surpassed ketchup in amount consumed in the United States (Johnson and Johnson, 1992). An increase in hot pepper acreage may be needed to meet the future demands of the spice and cooking trade.

The same cultural practices are often used for sweet peppers and hot peppers, but these crops differ in growth habits and fruiting characteristics. There are no previous reports outlining the N and K needs of Jalapeño peppers, although reports have documented N and K effects on sweet peppers (Jaworski et al., 1978). One of the few available reports stated that chili peppers grown with excess N ($N > 280 \text{ kg} \cdot \text{ha}^{-1}$) produced excessive foliage, apparently at the expense of fruit production (Stroehlein and Oebker, 1979).

Pungency of hot peppers is an important marketing characteristic and is determined by the production of capsaicinoids within the pod. Five analogs make up the collective term capsaicinoids: capsaicin, dihydrocapsaicin, nordihydrocapsaicin, homodihydrocapsaicin, and homocapsaicin (Govindarajan, 1986; Suzuki et al., 1981; Todd et al., 1977). Capsaicin is the predominant capsaicinoid and one of the most pungent compounds known, being detectable by the palate at dilutions of as little as $15 \text{ mg} \cdot \text{L}^{-1}$ (Bosland, 1992; Govindarajan, 1986; Govindarajan and Sathyanarayana, 1991; Govindarajan et al., 1987; Todd et al., 1977).

Practical concerns regarding hot pepper production have spurred interest in methods to environmentally enhance capsaicinoid production. Warm weather, poor soil, dry climates, and high night temperatures are suggested to favor the production of high capsaicin concentrations within the pods, although no research supports this suggestion. A strong correlation appears to exist between species, cultivar, and fruit maturity and pungency (Bajaj et al., 1980; Iwai et al., 1979). Potassium fertility affects pod pigment biosynthesis and may influence pungency because of its effect on enzymes (Trudel and Ozbun, 1970).

The objective of this research was to determine the influence of N and K fertility rates on Jalapeño pepper plant growth and development, pod yield, and pungency.

Materials and Methods

Plant material. 'Jalapa' pepper, an early maturing, compact fruiting Jalapeño type, was seeded into cell packs (96 cm^3 , $4 \times 4 \times 6 \text{ cm}$)

containing a peat and perlite medium of BX-Pro soilless mix (Premier Brands, Stamford, Conn.). The cell packs were placed in a greenhouse under fluorescent lights with a 14-h photoperiod with day/night cycles of about 30/20 °C. All plants were fertilized with a Peters 20N–8.7P–16.7K (20–20–20) (Grace-Sierra, Milpitas, Calif.) solution with micro-nutrients at $4 \text{ g} \cdot \text{L}^{-1}$ each day until transplanting. After 8 days, emerging seedlings were thinned to one plant per cell.

At the sixth true-leaf stage (≈ 30 days after seeding), the seedlings were transplanted to 16-L pots filled with coarse sand that was leached previously with deionized water. The pots were placed in the center of the greenhouse under HID (400-W metal halide, adding an additional $350 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ light) lights to provide a 14-h photoperiod for all experiments. Before transplanting, the medium was washed from the roots of the seedlings.

After transplanting, the seedlings were fertilized with 1.0 L of a complete Hoagland's #1 nutrient solution (Hoagland and Arnon, 1939), twice a day for the first 3 days; thereafter, the seedlings were fertilized every other day until initiation of experimental nutrient treatments. Plants received 1.0 L of deionized water on the days that nutrient solution was not applied.

Two experiments were conducted to determine Jalapeño pepper sensitivity to differential fertilization. In the first experiment (seeded 4 Apr. 1992), nutrient treatments began at transplanting, and in the second experiment (seeded 13 May 1992), treatments began after all plants had flower buds and half had flowered (≈ 30 days after transplant).

The potted plants were separated into two groups of 20 plants each, one group for the N and the other for K rate study. Each study was arranged in a randomized complete-block design, with four replications (one plant/replication).

Experimental nutrient treatments. The stock nutrient solution was a Hoagland's #1 nutrient solution minus the nutrient being investigated in the study. The nutrient being investigated was added at desired rates and from various sources (Tables 1 and 2) to the stock solution before application to the plants. For the N rate studies, we used 1, 7.5, 15, 22.5, and 30 mM, and the N sources were NaNO_3 , $\text{Ca}(\text{NO}_3)_2$, and KNO_3 . For the K rate studies, we used 1, 3, 6, 9, and 12 mM, and the K salts used were KNO_3 , KH_2PO_4 , and KCl. One liter of solution was applied on days 2, 4, and 6 each week. Solution pH for all treatments was 6.5.

Flower, pod, and biomass determinations. All flowers were tagged after pollination. A different-colored tag was used each week so that all the flowers that were hand-pollinated for the given week could be harvested at the same time.

About 30 days after pollination, pepper pods were harvested at weekly intervals. Fresh weights were taken and the fruit frozen at -80°C and freeze-dried. The fruit were then weighed and ground to pass through a $1.3 \times 1.3\text{-mm}$ mesh screen. The ground samples were then placed in a vacuum desiccator until they were analyzed for capsaicin and

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Table 1. Quantity of nutrients added to stock solution to achieve desired N concentration.

Nutrient Source	Desired N concn (mm)				
	1	7.5	15	22	30
	<i>Quantity added (mm/L)</i>				
KNO ₃	1	3	5	5	5
KH ₂ PO ₄	1	1	1	1	1
MgSO ₄	2	2	2	2	2
MICRO ^z	1	1	1	1	1
Fe	0.2	0.2	0.2	0.2	0.2
Ca(NO ₃) ₂	0	2.25	5	5	5
CaCl ₂	5	2.75	0	0	0
KCl	4	2	0	0	0
NaNO ₃	0	0	0	7.5	15

^zMicro elements were (mm) H₃BO₃, 4.627; MnCl₂·4H₂O, 0.92; ZnSO₄·7H₂O, 0.077; CuSO₄·5H₂O, 0.0349; NH₄MoO₃, 0.077.

Table 2. Quantity of nutrients added to stock solution to achieve desired K concentration.

Nutrient source	Desired K concn (mm)				
	1	7.5	15	22	30
	<i>Quantity added (mm/L)</i>				
KNO ₃	0	2	5	5	5
KH ₂ PO ₄	1	1	1	1	1
MgSO ₄	2	2	2	2	2
MICRO ^z	1	1	1	1	1
Fe	0.2	0.2	0.2	0.2	0.2
Ca(NO ₃) ₂	7.5	6.5	5	5	5
CaCl ₂	0	1	2.5	2.5	2.5
KCl	0	0	0	3	6

^zMicro elements were (mm) H₃BO₃, 4.627; MnCl₂·4H₂O, 0.92; ZnSO₄·7H₂O, 0.077; CuSO₄·5H₂O, 0.0349; NH₄MoO₃, 0.077.

Table 3. Influence of N and K rate when initiated at transplanting (Expt. 1) on plant biomass and pod production of Jalapeño peppers. Results are per plant.

Nutrient	Concn (mm)	Dry wt (g/plant)			Pod	
		Leaf	Stem	Total	No./plant	Dry wt (g)
N	1.0	5.8	5.0	10.8	4.3	62
	7.5	12.8	11.8	24.6	11.5	175
	15.0	19.1	13.1	32.2	17.8	291
	22.5	19.3	13.5	32.8	17.8	258
	30.0	11.9	8.3	20.3	5.5	117
Significance ^z		L ^{**} , Q ^{**}	L ^{**} , Q ^{**}	L ^{**} , Q ^{**}	L [*] , Q [*]	L ^{**} , Q ^{**}
K	1.0	10.1	5.3	15.4	9.8	80
	3.0	15.6	9.6	25.2	16.3	186
	6.0	27.6	19.2	46.8	21.5	251
	9.0	27.8	24.2	52.0	22.0	244
	12.0	32.9	25.2	58.1	22.8	249
Significance ^z		L [*]	L [*]	L [*]	L [*]	L ^{**}

^zQ = quadratic, L = linear.

^{*}, ^{**}Significant at $P \leq 0.05$ or 0.01, respectively.

dihydrocapsaicin. Capsaicin is a stable end-product and is not readily broken down unless heated to $>60^\circ\text{C}$ (Todd et al., 1977).

All studies were terminated 120 days after transplanting. Pods were harvested four times. At the completion of each study, the aerial portion of all plants was cut at the soil surface and separated into marketable pods (tagged and of a known age), nonmarketable pods, stems, leaves, and petioles. Fresh and dry weights were recorded. The leaves and petioles were ground with a Wiley mill to pass

through a 1.3×1.3 -mm mesh screen and analyzed for N and K, using the micro-Kjeldahl method (Bremner, 1965) and atomic absorption spectrophotometry, respectively.

Determination of pod pungency. Capsaicin was extracted from whole pod samples by placing 1.0 g of ground, freeze-dried pod sample into a 30-mL beaker containing 10 mL of acetonitrile. The mixture was blended for 90 s using a Polytron (Brinkman Instruments, Westbury, N.Y.). A 1-mL aliquot was removed and diluted with 9 mL of H₂O. A C18

Sep-pak solid phase extraction cartridge (200 mg; Burdick and Jackson, Muskegon, Mich.) was placed onto a vacuum chamber. The filter was conditioned using 5 mL of acetonitrile followed by 5 mL of double-distilled water. The diluted pepper sample was injected into the Sep-pak (10 mL of solution) for 10 min. After 10 min, the capsaicinoids were eluted using 4 mL of acetonitrile followed by 1 mL of acetonitrile containing 1% acetic acid. The sample eluate was then filtered through a 0.025- μm filter and placed in the freezer until analysis.

Capsaicin and dihydrocapsaicin were quantified using a modified method developed by Quinones-Seglie et al. (1989) and Weaver et al. (1984). Separation occurred on a Varian 5060 HPLC (Varian Instruments, San Fernando, Calif.) with a 10- μm Bondapak C18 column (Varian Instruments) and a guard column of Bondapak C18 corasil with UV absorption at 238 nm. The mobile phase was acetonitrile-water with 1% acetic acid (55:45), with a flow rate of 1.8 mL·min⁻¹, and a 50- μL loop. Samples had a run time of 15 min, with retention times of 5.25 and 7.08 min for capsaicin and dihydrocapsaicin, respectively, as determined by chromatography of known standards of 8-methyl-*N*-vanillyl-6-noneamide (capsaicin) and 8-methyl-*N*-vanillyl-6-nonanamide (dihydrocapsaicin) (Sigma Chemical Co., St. Louis). A CDS 402 Varian data system (Varian Instruments) measured peak area and height. This system had a detection limit of 10 mg·L⁻¹ with an efficiency of 95% to 98% of the standards recovered after processing. Capsaicin and dihydrocapsaicin account for more than 90% of the capsaicinoids in hot peppers and contribute most to the pungency (Todd et al., 1977). Other capsaicinoids were not consistently measurable with this method. Scoville values were calculated by multiplying the amount of capsaicin and dihydrocapsaicin per gram dry weight by 16 million Scoville units for pure capsaicin and dihydrocapsaicin (Todd et al., 1977).

Statistical analysis. Data were tested for analysis of variance and regression using SAS version 6.08 General Linear Models procedure (SAS Inst., Cary N.C.).

Results

Fertility treatments initiated at transplanting (Expt. 1)

Nitrogen rate. Nitrogen fertility rate begun at transplanting affected Jalapeño plant growth and pod production (Table 3). Plant biomass (dry weight) of leaves, stem, and pod (number and weight) per plant responded curvilinearly to N fertility rate.

Nitrogen fertility rate also affected the pungency of pods, as measured by capsaicinoid production and resulting Scoville units. Levels of capsaicin and Scoville units responded curvilinearly ($P \leq 0.05$) to N rate (Fig. 1A and C). Dihydrocapsaicin increased linearly ($P \leq 0.05$) with increasing N rate up to 15 mm and then levelled off (Fig. 1B).

Fig. 1. Response of pungency to N in Expt. 1 (seeded 4 Apr. 1992), when nutrient treatments began at transplanting.

Nitrogen concentration of leaves increased linearly ($P \leq 0.05$) with increasing N rate up to 15.0 mM and then levelled off (Fig. 2A). Plants treated with 22.5 mM N had higher N levels in petioles than plants treated with 15 mM N (data not presented). Nitrogen content of petioles of plants treated with 1, 7.5, or 30 mM N was not determined because of insufficient petiole tissue.

Potassium rate. Biomass and fruit production per plant increased linearly with increasing K rate (Table 3). Potassium fertility rate had no effect of pungency of the pod (data not presented). Potassium levels in leaves and petioles increased linearly ($P \leq 0.05$) as K rate increased up to 6 mM and then levelled off (Fig. 2B).

Fertility treatments initiated at flowering (Expt. 2)

Nitrogen rate. Nitrogen fertility affected Jalapeño plant biomass and pod production (Table 4). Leaf, stem, and total biomass and pod count per plant responded curvilinearly to N fertility rate. Nitrogen treatments initiated at flowering did not affect pungency of the pod (data not presented). Nitrogen concentration of petioles and leaves increased linearly with increasing N rate (Fig. 3A).

Potassium rate. Leaf and total biomass per plant responded curvilinearly to K rate (Table 4). Stem biomass increased linearly with increasing K rate. Potassium rate did not affect pod count and dry weight per plant. Potassium rate did not affect pungency of the pod (data

not presented). Levels of K in the leaves and petioles increased linearly ($P \leq 0.05$) as K fertility increased (Fig. 3B).

Discussion

Plant biomass. The lower and higher rates of N evaluated were undesirable for plant growth in both experiments. The best N fertilization rates that enhanced growth were between 15.0 and 22.5 mM with a leaf N concentration of 3.8% to 4.2% of dry weight. Nitrogen concentration affected Jalapeño plant growth more in Expt. 1 (when plants were seeded in April and nutrient treatments began at transplanting) than in the second experiment (when plants were seeded in May and nutrient treatments began at flowering). Because of the different seeding dates of the experiments, we are not able to conclude that this difference in plant response to N was due to the stage of plant development when the treatments were initiated.

Plants treated with 1 mM N were stunted in both experiments. Previous reports (Batal and Smittle, 1981; Jaworski et al., 1978; Kafkafi, 1990; Knavel, 1977; Miller et al., 1979; O'Sullivan et al., 1974) suggested that bell peppers deficient in N were stunted and light green. The larger plants, i.e., those with the higher N rates, were easier to harvest and were able to withstand multiple harvests. Another advantage to greater vegetative growth would be fewer pods with solar injury. Thus, it is necessary to produce plants with sufficient foliage that optimizes pod development and quality.

Potassium rates evaluated were not toxic to plant development. As K rates increased, the plants accumulated K (Figs. 2B and 3B) without growth reduction. Jalapeño pepper plants receiving 1 mM K in both experiments were smaller than plants in the other K treatments. At least 6 mM K was needed for acceptable biomass development.

Yield. At least 7.5 but not more than 22.5 mM N was required for optimal pod production. The range 15 to 22 mM N gave the largest increase of pods per unit N. There was a direct correlation between plant growth and fruit production ($r = 0.93$ and 0.97 for Expts. 1 and 2, respectively). This finding contrasts with results of Mills and Jones (1979) with bell peppers and Stroehlein and Oebker (1979) with chili peppers that indicated excessive N treatments stimulated vegetative growth and reduced flowering.

The effects of N rate on pod yield were more apparent in Expt. 1. Plant biomass and pod production were highly correlated ($r = 0.97$); i.e., the plants with more leaf biomass supported more pods. Jaworski et al. (1978) reported that N at $4.5 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$ applied through a drip irrigation system produced highest Hungarian yellow wax pepper yields. For field-grown Tabasco peppers, red pepper yields increased with an increase in soil-applied N from 0 to $112 \text{ kg} \cdot \text{ha}^{-1}$ (Sundstrom, 1984).

In this study optimal pod production required at least 3 mM K. K in excess of 3 mM did not increase pod production. It appeared that K

Fig. 2. Influence of N and K rate in Expt. 1 (seeded 4 Apr. 1992), when nutrient treatments began at transplanting, on tissue nutrient concentration of Jalapeño pepper.

Table 4. Influence of N and K rate when initiated at flowering (Expt. 2) on plant biomass and pod production of Jalapeño peppers. Results are per plant.

Nutrient	Concn (mM)	Dry wt (g/plant)			Pod	
		Leaf	Stem	Total	No./plant	Dry wt (g)
N	1.0	8.8	11.2	20.0	10.5	139
	7.5	22.0	26.2	48.2	32.8	507
	15.0	32.9	37.2	70.1	42.5	539
	22.5	32.9	35.3	68.3	32.3	548
	30.0	34.2	35.7	69.8	34.5	516
Significance ^z		L*, Q*	L*, Q*	L*, Q*	L*, Q*	L*
K	1.0	16.4	14.0	30.4	29.3	466
	3.0	23.7	24.5	48.2	44.8	719
	6.0	30.4	31.8	62.3	39.3	614
	9.0	31.9	33.9	65.8	41.0	661
Significance		L**, Q*	L*	L*, Q*	NS	NS

^zQ = quadratic, L = linear.

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

deficiency is problematic only if the stress is for a long duration (e.g., initiated at transplanting). Short-term stresses likely will not cause reductions in yield except in cases when soil solutions fall below a critical minimum.

Pungency. Nitrogen treatments affected pod pungency only in Expt. 1. The curvilinear response of capsaicin and Scoville units to N fertility rate suggested that the optimum N

fertilizer rate to enhance pungency was between 7.5 to 22.5 mM. Dihydrocapsaicin levels in the fruit increased as N fertility rate increased. These results are in contrast to the suggestion that pungency increases in response to low N (poor soils).

We conclude that Jalapeño peppers grown in sand culture require 15 mM N and at least 6 mM K for optimum fruit production and be-

tween 7.5 to 22.5 mM N for optimum pod pungency.

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Fig. 3. Influence of N and K rate on tissue N and K concentration of Jalapeño pepper in Expt. 2 (seeded 13 May 1992), when nutrient treatments began after all of the plants had flower buds and half had flowered (≈ 30 days after transplant),

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