Pumpkin Growth, Flowering, and Fruiting Response to Nitrogen and Potassium Sprinkler Fertilization in Sandy Soil

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Abstract. Field studies were conducted in 1987 and 1988 to determine the effect of various sprinkler-applied N–K fertigation treatments and 196N–280K (kg·ha−1) dry-blend application on pumpkin (Cucurbita moschata Poir.) flower development, fruit set, vine growth, and marketable yield response in a Plainfield sand. The number of male and female flowers that reached anthesis by 72 days after seeding (DAS) was highest with either 112N–112K or 112N–224K fertigation. Fertigation using either 56N–112K or 168N–224K delayed the start of flowering and reduced the total number of male and female flowers produced by 72 DAS. Fruit set decreased at the low N–K fertigation rate (56N–112K), but otherwise was unaffected by N–K fertility regime. Vine dry weight and stem elongation increased as the N fertigation rate increased, with relatively little effect from fertigated K. There was no field indication of excessive vegetative growth in any of the fertigation treatments. Highest yields of early set marketable fruit (pumpkins that set before 65 DAS), and total marketable yields were obtained with fertigation of 112N, in combination with either 112 or 224 kg·ha−1 fertigated K. Usable green and cull fruit production increased with increasing N–K fertigation rate. Dry-blend application of 196N–280K decreased early and total yields significantly. The results showed that sprinkler-applied 112N–112K split into five fertigations during the growing season (supplemented with a preplant dry-blend application of 28N–56K) produced high yields without compromising early fruit maturity.

Illinois leads the United States in the production of processing pumpkins, with the commercial acreage (=4000 ha) evenly distributed between irrigated production on sandy soils, used for the early crop, and dryland culture on heavy-textured soils, used for the main-season and late crops. On sandy soils, it is becoming common practice to apply most of the N and K fertilizer in several increments during the growing season with the irrigation water, using overhead center-pivot sprinkler systems, in addition to a small amount of granular, or dry-blend, fertilizer applied before planting.

Commonly referred to as fertigation or chemigation, application of fertilizer with irrigation water has several inherent advantages over conventional dry-blend fertilization for crop production on coarse-textured soils, including lower fertilizer inputs, reduced nutrient leaching, and flexibility in scheduling to meet crop demands (Rehm and Wiese, 1975; Saffigna and Keeney, 1977; Watts and Martin, 1981). For pumpkin production, in particular, fertigation can be a very accurate method for uniform applications of in-season N and K during early fruit development, when N and K requirements are highest (Swiader, 1985), and when sidedressing of granular fertilizer is not possible after vines start to run and fill in between the rows. However, when fertigating N and K, pumpkin growers frequently complain of delayed fruit development. Field observations tend to implicate excessive vegetative growth and inconsistent flowering as causal factors, although there are no data to support this.

Research with other cucurbits has shown an interaction between N fertilization and sprinkler irrigation, with an optimum application of N for a given level of irrigation (Flocker et al., 1965; Smittle and Threadgill, 1982). In previous work with pumpkins on irrigated sand using dry-blend fertilizer application, estimated maximum yields occurred at 225 kg N/ha, although at N rates >134 kg/ha the relative yield response was small (Swiader et al., 1988). Furthermore, fruit set and harvest were delayed 8 and 9 days, respectively, from application of 202 kg N/ha, thereby offsetting the small yield increase at higher N rates.

Little information, if any, is available regarding N and K fertigation requirements for pumpkins. Fertigation practices vary widely, with growers applying up to 150 kg N/ha and 200 kg K/ha to the crop. The objective of this study was to determine the rates of fertigated N–K required for high early and total yields of pumpkins in sandy soil. The effect of N–K fertigation on pumpkin vine growth, flower production, and fruit development was also evaluated. Since some production areas still use considerable granular fertilization, an additional objective was to compare dry-blend application with N–K fertigation for its effect on pumpkin growth, flowering, and yield response.

Materials and Methods

Field studies were conducted in 1987 and 1988 at the Illinois River Valley–Univ. of Illinois Sand Field in Kilbourne, Ill. The soil at the site was a Plainfield sand (sandy, mixed, mesic Typic Udipsamment), characterized by low organic-matter content (0.5%) and low nutrient-holding capacity (CEC 2.5 meq/100 g). During the fall before each study, the site was seeded with a rye (Secale cereale L.) cover crop, which was plowed into the soil in April. In Fall 1986, ground calcitic limestone (6 t·ha−1) was broadcast and incorporated in the upper 20 cm of soil to adjust the soil pH to 6.8. One week before planting, all plots were fertilized with P at 56 kg·ha−1 as concentrated-superphosphate, and Mg at 22 kg·ha−1 as MgSO4.

Each year, treatments included three N–K fertigation combinations and one dry-blend N–K application, based on current com-
Fertility regimes for pumpkin (Table 1). In 1987, 166-m² (18.2 × 9.1 m) plots were included in a randomized complete-block design with three replications. In 1988, there were four replications. Fertigated N and K were applied as urea–ammonium nitrate and KCl, respectively, using a combination portable-pipe and overhead sprinkler system fitted with Venturi-type fertilizer injectors. Fertilization applications were made by injecting measured volumes of the appropriate fertilizer mixture into an 0.8-cm irrigation line running down the center of each plot. To avoid N and K accumulation, a minimum of 10 min of irrigation rinse followed each application. Dry-blend N and K was applied as NH₄NO₃ and KCl. All preplant dry-blend N and K was broadcast and disked into the top 30 cm of soil. In-season dry-blend N and K was banded on the soil surface ≈15 cm from the plants and lightly incorporated into the soil. During fertigation of N and K, plots that received the dry-blend treatment were irrigated at the same time and rate as fertigated plots. Additional irrigation was applied to all plots to provide a total (including rainfall) of 3.8 cm of water per week.

In May of each year, ‘Libby-Select’ pumpkin was seeded by hand at 0.46-m intervals in double rows 1.5 m apart (spaced on either side of the irrigation line) and 12.2 m long in the center of each plot. When seedlings developed two true leaves, hills were thinned to one plant, resulting in a stand of 54 plants per plot, or ≈7300 plants/ha. (Note that this approximation is based on an area of 12.2 m × 6.1 m and disregards a buffer zone, 3.0 m on each end and 1.5 m on each side, which was used to limit the effects of plants in neighboring plots.)

Beginning with anthesis of the first flowers, and continuing until 72 days after seeding (DAS), all newly emerging male and female flowers were marked with designated colored plastic flags in conjunction with 112N–56K, and lowest with 56N–112K, where plants averaged less than one female flower each. In 1988, flower production was similar in the 112N–112K and 112N–224K treatments, but decreased significantly at the high N fertigation rate (168N–224K). Increasing K fertigation rate from 56 to 112K, flower production was similar in the 112N–112K and 112N–224K treatments and which were ripe at harvest); and usable-green fruit (immature fruits >15 cm in diameter that were suitable for mechanical harvest and processing). Fruits <15 cm in diameter were considered culls, in addition to any split or unusable larger fruits. Plastic flags without an accompanying fruit were counted as female flowers that failed to set fruit.

Plant samples were dried in a forced-air oven at 70°C for 48 h. Total N was determined using a modified micro-Kjeldahl digestion procedure (Nelson and Sommers, 1980), in conjunction with an indolephenol-blue colorimetric assay (Cataldo et al., 1974). Tissue K concentration was measured using flame emission photometry following HNO₃–H₂O₂ digestion. Soluble solids were measured with a refractometer for three randomly selected fruit per plot for each maturity period. The data were evaluated by analysis of variance. The time course of daily flower development up to 72 DAS was characterized in each of the N–K treatments by regression analysis using the GLM procedure (Spector et al., 1985).

Results and Discussion

Flower development. Significant differences in pumpkin flower production were found among fertigation treatments in both years (Table 2). In 1987, the number of male and female flowers that reached anthesis by 72 DAS was highest with 112N–112K fertigation, intermediate with 112N–56K, and lowest with 56N–112K, where plants averaged less than one female flower each. In 1988, flower production was similar in the 112N–112K and 112N–224K treatments, but decreased significantly at the high N fertigation rate (168N–224K). Increasing K fertigation rate from 56 to 112K, in conjunction with 112N, increased male flower production in 1987, but otherwise there was relatively little effect of K fertigation on flower development up to 72 DAS. In both years, male and female flower production was greater with 112N–112K fertigation than with the dry-blend application. There were no differences between treatments in male to female flower ratio, with plants producing ≈10 male flowers to each female flower.

The earliest appearance of male and female flowers was in the 112N–112K and 112N–224K fertigation treatments (Table 2). Days to first male and female flowers increased at both high (168N–224K) and low N fertigation (56N–112K) rates. Compared to the 112N–112K treatment, initial anthesis of male and female flowers was delayed 6.5 and 7 days, respectively, with 168N–224K, and 9.8 and 9.0 days, respectively, with 56N–112K. Node number of first female flowers also increased at the high fertigation.
However, despite the significant delay in flowering from 168N–224K fertigation, the relative rates of male and female flower production were similar to those with 112N–112K, indicating that once flowering was initiated, further flower development was not inhibited by high N–K fertigation rates. This effect did not carry over to the low N fertigation regime, where the relative rates of male and female flower production were markedly decreased by fertigation of 56N–112K.

Regression analysis of daily female flower production on days after initial anthesis showed a quadratic pattern of flower development in each treatment (Fig. 1). The period of highest female flower production in the 112N–112K and 112N–224K treatments occurred 15 and 19 days after initial anthesis, or ≈65 and 69 DAS, respectively. In both the dry-blend and 168N–224K treatments, peak female flower production occurred later in the season, ≈23 days after initial anthesis, or 76 and 79 DAS, respectively. The relationship between daily male flower production and days after initial anthesis was generally linear, with the number of staminate flowers produced per day increasing as days after initial anthesis increased (Fig. 2). In several of the treatments, a stair-step pattern in male flower development was observed, particularly in 1987. Although the exact nature of this response is not clear, it appeared that this pattern was most prevalent later in the season when the production of staminate flowers was highest, indicating that a heavy flower load may have been a contributing factor. The relatively flat slope of the 56N–112K regression line in 1987 for female flowers, and the stair-step response in male flowers with 56N–112K and 112N–56K, suggested that plants in these treatments were having difficulty producing flowers.

Fruit set. With the exception of the low N fertigation treatment (56N–112K), fruit set was not significantly affected by N–K fertilization regime (Table 2). Failure of most early flowers to set fruit was generally attributable to poor pollination due to unfavorable weather conditions (cool temperatures and cloudy overcast days) during anthesis (Jaycox, 1978). The relatively high level of fruit set in both the dry-blend and 168N–224K fertigation treatments indicated that high initial N rates did not have an adverse effect on early fruit development. The low percentage of fruit set in the 56N–112K treatment most likely reflected the poor condi-

![Fig. 1. Relationship between daily female flower production and days after initial anthesis, in response to various N–K fertilization regimes in 1987 and 1988. Regression equations for the lines shown were as follows: 1987—56N–112K, y = 0.047 + 0.0068x–0.00035x² (R² = 0.28); 112N–56K, y = 0.049 + 0.0163x–0.00067x² (R² = 0.47); 112N–112K, y = 0.041 + 0.0178x–0.00066x² (R² = 0.41); 196N–280K, y = 0.033 + 0.0086x–0.00003x² (R² = 0.62); 1988—112N–112K, y = 0.014 + 0.0198x–0.00057x² (R² = 0.64); 112N–224K, y = 0.033 + 0.0144x–0.00038x² (R² = 0.66); 168N–224K, y = 0.034 + 0.014x–0.0003x² (R² = 0.72); 196N–280K, y = 0.040 + 0.0073x–0.00015x² (R² = 0.52).

![Table 2. Effect of N–K fertilization regime on pumpkin flower response and fruit set through 72 days after seeding (DAS) in 1987 and 1988.](image-url)
by 72 DAS plant growth was clearly stunted. There was no field indication of excessive vegetative growth in any of the fertigation treatments. Analysis of pumpkin growth components showed that the increased growth response with 168N–224K fertigation was due to an increase in the number of nodes, whereas in the 196N–280K dry-blend treatment, enhanced vine growth resulted from increases in both node number and internode length.

Similar to the response in the various growth parameters, leaf N concentrations generally increased with increasing N fertigation rate, with little effect from fertigated K (Table 4). In both years, leaf N concentrations at 46 DAS were highest with the dry-blend application, but by 72 DAS, tissue N levels were comparable in the dry-blend treatment and several of the fertigation treatments. Although K fertigation had little influence on vine growth, leaf K content at each sampling date increased as K fertigation rate increased. In each treatment, leaf N and K levels tended to decrease as the season progressed, with the largest reductions occurring with the dry-blend application. By 90 DAS, leaf N and K concentrations were greater with 112N–112K fertigation than with the dry-blend application, and were within the general ranges previously reported for pumpkins on irrigated soil (Swiader, 1985).

**Yield response.** Highest yields of early-set marketable fruit (fruits that set before 65 DAS) were obtained with fertigation of 112N, in combination with either 112 or 224K; the small yield decrease with 112N–56K relative to 112N–112K in 1987 was significant at the 10% level of probability (Table 5). Although there was a statistically significant increase in the average size (kg/fruit) of early set fruit with the dry-blend application vs. several of the fertigation treatments, in most cases this increase was of minor practical importance. Fertigation of either 56N–112K or 168N–224K decreased the yield and number of early set fruit significantly. The notably large size of early set pumpkins in the 56N–112K treatment reflected the very small fruit load that developed at the low N fertigation rate (Brinen et al., 1979). Overall, yields of early set fruit accounted for 47% of the total marketable weight produced with 112N (data pooled over K fertigation rates), 39% with the 196N–280K dry-blend application, and ≈24% with either 168N–224K or 56N–112K.

Mid-season fruit production (represented by pumpkins set after 64 DAS, and which were ripe at harvest) was similar in both years in the 112N–112K fertigation and the dry-blend treatments (Table 5). Fertigating 56N–112K, 112N–56K, or 168N–224K decreased the yield of mid-season-set fruit, but had little effect on fruit number. The concomitant reduction in fruit size and total yield of mid-season-set pumpkins with 112N–56K, coupled with the rela-

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**Table 3. Effect of N–K fertilization regime on pumpkin vegetative growth components at 72 days after seeding (DAS) in 1987 and 1988.**

| N–K fertilization (kg·ha⁻¹) | Vine dry wt (g/plant) | Vine stem length (cm) | Vine node no. | Avg node length (cm) |
|-----------------------------|-----------------------|-----------------------|--------------|---------------------|
| 56–112 Fertigation          | 100 c                 | 171.5 c               | 25.0 c       | 6.8 b               |
| 112–56 Fertigation          | 241 b                 | 307.8 b               | 38.5 b       | 8.0 ab              |
| 112–112 Fertigation         | 271 b                 | 325.0 b               | 42.8 ab      | 7.6 b               |
| 196–280 Dry-blend           | 357 a                 | 468.1 a               | 48.8 a       | 9.6 a               |
| 112–112 Fertigation         | 316 b                 | 409.0 b               | 46.5 b       | 8.8 b               |
| 112–224 Fertigation         | 339 b                 | 459.7 b               | 50.0 b       | 9.2 ab              |
| 168–224 Fertigation         | 420 a                 | 558.5 a               | 62.0 a       | 9.0 ab              |
| 196–280 Dry-blend           | 481 a                 | 611.8 a               | 58.3 a       | 10.5 a              |

*For each year, mean separation within columns by LSD at P = 0.05.*
or 112N–224K (Table 5). Due to the stimulation of usable-green splitting of larger fruits (Flocker et al., 1965).

The total marketable yield with either 112N–112K or 112N–224K fertigation was higher than significantly larger fruit size (kg/fruit) or differences in fruit maturity period (data not shown), the increases in total marketable yield with either 112N–112K or 112N–224K fertigation were attributed to a greater number of marketable fruit, rather than significantly larger fruit size (kg/fruit) or differences in fruit composition.

Table 4. Effect of N–K fertilization regime on pumpkin leaf N and K concentrations at 46, 72, and 90 days after seeding (DAS) in 1987 and 1988.

| N–K Fertilization (kg·ha⁻¹) | Leaf N (% dry wt) 46 DAS | Leaf N (% dry wt) 72 DAS | Leaf N (% dry wt) 90 DAS | Leaf K (% dry wt) 46 DAS | Leaf K (% dry wt) 72 DAS | Leaf K (% dry wt) 90 DAS |
|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 56–112 Fertigation 9.3 c w 1129 c 8.18 a | 2.48 c² | 2.27 b | 1.83 c | 2.70 c a 4.17 a | 2.98 b | 3.12 b | 3.00 a | 2.85 a |
| 112–56 Fertigation 34.2 a 5844 a 5.85 c | 4.24 b | 4.03 a | 3.37 a | 4.58 a | 4.22 a | 4.17 a | 4.44 a | 4.60 a |
| 112–112 Fertigation 39.5 a 6376 a 6.17 c | 4.11 b | 3.83 a | 3.66 a | 4.58 a | 4.22 a | 4.11 a | 4.34 a | 4.54 a |
| 196–280 Dry-blend 4.79 a 4.17 a | 39.5 a 6376 a 6.17 c | 4.11 b | 3.83 a | 3.66 a | 4.58 a | 4.22 a | 4.11 a | 4.34 a |

Table 5. Effect of N–K fertilization regime on pumpkin marketable fruiting response and cull production in 1987 and 1988.

| N–K Fertilization (kg·ha⁻¹) | Early set marketable fruit¹ Yield (t·ha⁻¹) | Early set marketable fruit¹ Fruit Wt (kg/fruit) | Mid-season-set marketable fruit³ Yield (t·ha⁻¹) | Mid-season-set marketable fruit³ Fruit Wt (kg/fruit) | Usable green fruit² Yield (t·ha⁻¹) | Usable green fruit² Fruit Wt (kg/fruit) | Total marketable yield² Yield (t·ha⁻¹) | Total marketable yield² Fruit (no./ha) | Culls (%) |
|----------------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------------|----------------------------------|------------------------------------|-----------------------------------|-----------|
| 56–112 Fertigation 9.3 c² | 1129 c 8.18 a | 18.3 b 3919 a 4.69 b | 9.6 b 2125 a 4.54 a | 37.3 c 7173 c 5.4 b | 9.3 c w 1129 c 8.18 a | 18.3 b 3919 a 4.69 b | 9.6 b 2125 a 4.54 a | 37.3 c 7173 c 5.4 b |
| 112–56 Fertigation 34.2 a 5844 a 5.85 c | 22.0 b 4516 a 4.87 b | 11.5 ab 2749 a 4.19 a | 67.7 b 13109 a 9.7 a | 34.2 a 5844 a 5.85 c | 22.0 b 4516 a 4.87 b | 11.5 ab 2749 a 4.19 a | 67.7 b 13109 a 9.7 a |
| 112–112 Fertigation 39.5 a 6376 a 6.17 c | 27.4 a 4051 a 6.75 a | 15.0 a 3370 a 4.46 a | 81.9 a 13797 a 11.0 a | 39.5 a 6376 a 6.17 c | 27.4 a 4051 a 6.75 a | 15.0 a 3370 a 4.46 a | 81.9 a 13797 a 11.0 a |
| 196–280 Dry-blend 24.5 b 3676 b 6.73 b | 32.5 a 4583 a 7.08 a | 6.5 c 1303 c 5.01 a | 63.5 b 9539 a 3.6 b | 24.5 b 3676 b 6.73 b | 32.5 a 4583 a 7.08 a | 6.5 c 1303 c 5.01 a | 63.5 b 9539 a 3.6 b |

Footnotes: ¹For each year, mean separation within columns by LSD at P = 0.05. ²For each year, mean separation within columns by LSD at P = 0.05. ³For each year, mean separation within columns by LSD at P = 0.05.
168N–224K, delayed flowering at the high N–K fertigation rate did not allow sufficient time for fruit ripening, resulting in high amounts of immature fruit at harvest. Sprinkler-applied 112N–112K split into five fertigations during the growing season (supplemented with a preplant dry-blend application of 28N–56K) produced high yields without compromising early fruit maturity. Dry-blend application of 196N–280K decreased early and total yields significantly.

These results indicate that effective N–K fertigation for pumpkin production on sandy soil would be at considerably lower rates than current dry-blend fertilization practices. Properly managed, N–K fertigation should reduce ground water pollution, particularly with nitrates, without jeopardizing pumpkin yields. Different rates and timings of fertigated N–K than those evaluated here may further enhance early and total pumpkin yields.

**Literature Cited**

Brinen, G.H., S.J. Locascio, and G.W. Elmstrom. 1979. Plant and row spacing, mulch and fertilizer rate effects on watermelon production. J. Amer. Soc. Hort. Sci. 104:724–726.

Cataldo, D.A., L.E. Schrader, and V.L. Young. 1974. Analysis by digestion and colorimetric assay of total nitrogen in plant tissues high in nitrate. Crop Sci. 14:854-856.

Flocker, W.J., J.C. Lingle, R.M. Davis, and R.J. Miller. 1965. Influence of irrigation and nitrogen fertilization on yield, quality, and size of cantaloupes. Proc. Amer. Soc. Hort. Sci. 86:424–432.  

Jaycox, E.R. 1978. Pollination of fresh vegetables and canning crops. In: J.W. Courter (ed.). Proceedings 1978 Illinois vegetable growers schools. Univ. Ill. Coop. Ext. Serv.

Nelson, D.W. and L.E. Sommers. 1980. Total nitrogen analysis of soil and plant tissues. J. Assn. Offic. Anal. Chem. 63:770–778.

Rehm, G.W. and R.A. Wiese. 1975. Effect of method of nitrogen application on corn (Zea mays L.) grown on irrigated sandy soils. Soil Sci. Soc. Amer. Proc. 39:1217–1220.

Saffinga, P.G. and D.R. Keeney. 1977. Nitrogen and chloride uptake by irrigated Russet Burbank potatoes. Agron. J. 69:258–264.

Smittle, D.A. and E.D. Threadgill. 1982. Response of squash to irrigation, nitrogen fertilization, and tillage systems. J. Amer. Soc. Hort. Sci. 107:437–440.

Spector, P.C., J.H. Goodnight, J.P. Sall, and W.S. Sarle. 1985. The GLM procedure. In: A.A. Ray (ed.). SAS user’s guide: Statistics. SAS Inst., Cary, N.C. p. 433–506.

Swiader, J.M., J.G. Sullivan, F.G. Freijii, and J.A. Grunau. 1988. Nitrate monitoring for pumpkin production on dryland and irrigated soil. J. Amer. Soc. Hort. Sci. 113:684–689.

Swiader, J.M. 1985. Seasonal growth and composition and accumulation of N–P–K in dryland and irrigated pumpkins. J. Plant Nutr. 8:909–919.

Watts, D.A. and D.C. Martin. 1981. Effects of water and nitrogen management on nitrate leaching loss from sand. Trans. Amer. Soc. Agr. Eng. 4:911–916.

Whitaker, T.W. and G.N. Davis. 1962. Cucurbits. Leonard Hill Interscience, New York.