Nitrogen is a critically important nutrient in pumpkin production, both from a yield and a maturity perspective. While too little N can result in reduced fruit size and low yields, excess N can delay flowering, causing high amounts of green fruit at harvest at the expense of ripe fruit production (Swiader et al., 1994). Additionally, N is also a major factor from an environmental standpoint. In Illinois, surface water N is dominated by agricultural sources, with the most important being N runoff from excess fertilizer rates (David and Gentry, 2000). This situation is of particular concern in tile-drained production areas of the state (≤25% of Illinois), where tiles take shallow groundwater from the bottom of the root zone and deliver it to streams that feed into surface water reservoirs, leading to NO₃-N concentrations >10 mg·L⁻¹ in more than 30% of the sites tested (David et al., 1997). In context of these mutual environmental and production consequences of mismanaged N fertilization, N fertilizer-use efficiency has become a major goal of Illinois pumpkin production.

Nitrogen fertilizer-rate studies for pumpkins are relatively few, with varying results. In Illinois, fertilizer N requirements for 90% and 100% pumpkin yield (Cucurbita moschata) ranged from 44 and 158 kg·ha⁻¹ N, respectively, on a dryland silty-clay loam (Swarth et al., 1988), to 148 and 245 kg·ha⁻¹ N, respectively, on a ferralitic fine-sand (Swiader and Moore, 2002). In New York, pumpkin (Cucurbita pepo L.) yield at two sites, one on a silt loam and the other on a sandy loam, was unaffected by three rates of N (67, 112, 157 kg·ha⁻¹ N); however, a 0 kg·ha⁻¹ N control was not reported at either location, making interpretation of results difficult (Reiners and Rigg, 1997).

When determining optimum N fertilization rates, producers should consider past cropping history. Studies commonly show that legumes can contribute up to 100 to 130 kg·ha⁻¹ N to succeeding non-leguminous crops, significantly affecting fertilizer N requirements (Kurtz et al., 1984). In potato (Solanum tuberosum L.), optimum fertilizer N rates over a 3-year period averaged 72.5 kg·ha⁻¹ N lower following red clover (Trifolium pratense L.) than following small grains (Porter and Sisson, 1991). Similarly, the optimal N rate for corn following soybean was 47 kg·ha⁻¹ N lower than for corn following corn, even though yields were similar (Nafziger et al., 2000). Known as the “N rotation effect,” most N benefits using legumes in crop rotations are attributed to increased levels of residual soil NO₃-N in the spring following legumes (Badaruddin and Meyer, 1994; Franzleubbers et al., 1994).

In Illinois, pumpkins are traditionally grown in rotation with corn and soybeans, with pumpkins sometimes following corn or 2-years corn, and other times following soybeans. Based on research with other crops, fertilizer N requirements are likely to vary, depending on cropping sequence. Soybean N-credits to ensuing crops typically range from 11 kg·ha⁻¹ N for wheat (Triticum aestivum L.) and other small grains to 45 kg·ha⁻¹ N for corn (Hoefi and Peck, 1998), with some estimates in corn as high as 90 kg·ha⁻¹ N (Nafziger et al., 1984). Soybean N-credits specific for pumpkins have not been reported. The objective of this study was to determine optimal fertilizer N requirements in pumpkin, taking into account previous crops of corn and soybeans, and any rotational N-credits. In the process, the relationship between residual soil NO₃-N levels and pumpkin yield response to N fertilizer was evaluated over a range of cropping systems.

Materials and Methods

A series of field experiments were conducted over a 5-year period (1994–98) at the Univ. of Illinois Vegetable Crops Research Farm in Champaign, in which pumpkin was grown in rotation with corn or soybean. The soil at the site was a Flanagan silty loam (fine, montmorillonitic, mesic Aquic Argudolls), along with some smaller areas of Drummer silty clay loam (fine-silty, mixed, mesic Typic Haplauquoll) and Catlin silt loam (fine-silty, mixed, mesic, Typic Argudolls). Each of the soils at the site had no history of manure application.

Treatments consisted of a factorial combination of five N fertilization rates (0, 56, 112, 168, 224 kg·ha⁻¹ N) and four pumpkin cropping systems (rotations): 1) pumpkins following corn; 2) pumpkins following soybeans; 3) pumpkins following 2-years corn; and 4) pumpkins following fallow ground. The cropping systems were chronologically and spatially arranged in two separate series, so as to allow two complete cycles with two autonomous pumpkin studies, one in 1996 and the other in 1998. In each study, a split-plot design was used, with pumpkin cropping systems as main plots, replicated four times, and N rates as subplots (11.0 m x 4.6 m). Corn and soybeans in main plots were grown using standard industry procedures (Illinois Agronomy Handbook, 1992), with broadcast application of 168 kg·ha⁻¹ N made to corn and no N applied to soybeans. Following harvest of grain, corn and soybean plant residues were disked in the soil.

On 20 May 1996 and 26 May 1998, pumpkin ‘Libby-Select’ was machine-seeded in each N subplot in six rows 4.6 m long, spaced 1.8 m apart, with seeds spaced 0.25 m apart in each row. When seedlings developed two true leaves, plants were thinned to an in-row spacing of 0.5 m, resulting in a final pumpkin population of ≈10,750 plants ha⁻¹. About 1 week prior to seedling pumpkins, N fertilization rates were applied to...
as urea-ammonium nitrate solution (28–0–0) broadcast and incorporated (15 cm) in the soil. Maintenance applications of P and K and other cultural requirements were in accordance with standard commercial pumpkin recommendations (Midwest Vegetable Production Guide, 1995). Overhead sprinkler irrigation was applied to provide a total (including rainfall) of ≈3.8 cm of water per week.

Weather conditions during the 1996 growing season were very conducive to pumpkin production, but lesser so in 1998. In both years, mean monthly air temperatures during the growing season were comparable to the 20-year average, except in Sept. 1998 where temperatures averaged 3.4 °C higher than normal (Table 1). Seasonal rainfall totaled 61.6 cm in 1996 and 69.6 cm in 1998, compared to the previous 20-year mean of 62.2 cm. In both years, rainfall totals were higher than normal, especially in 1996 with more than 20 cm of precipitation. This pattern continued in June 1998, with more than 2 times the normal precipitation occurring during the critical periods of female flowering and fruit set.

Pumpkin fruits were harvested (12 Sept. 1996; 1 Oct. 1998) by hand from the middle 3.7 m × 4.6 m of each subplot when it was estimated that 80% of the primary fruits had reached commercial maturity, as indicated by a change in rind color from green to tan. The number and total weight of ripe and usable green fruit were recorded. Non-usable fruit, including split and small fruit (<15-cm diameter), were not harvested. In Spring 1996 and 1998, about 1 week before seeding pumpkins and just prior to application of N rates, a composite sample of 12 to 18 soil cores (2.5-cm diameter) was collected from each main plot to a depth of 30 cm and stored at −20 °C. When ready for analysis, soil samples were thawed and air-dried in the greenhouse, screened, and thoroughly mixed. Triplicate subsamples were analyzed for organic matter content by a modified Walkley-Black method (Schulte, 1988), total-N by salicylic acid-thiosulfate-H2SO4 digestion (Bremner and Mulvaney, 1988), total-N by salicylic acid-thiosulfate-H2SO4 digestion (Bremner and Mulvaney, 1988), and total-N by salicylic acid-thiosulfate-H2SO4 digestion (Bremner and Mulvaney, 1988), and colorimetric determination of nitrogenous compounds in the extracts (Cataldo et al., 1975). Analyses for organic matter and total N were performed on soil particles <0.6-mm diameter, and NO3-N analysis on <2-mm diameter.

Data were evaluated by analyses of variance. When significant treatment effects (P ≤ 0.05) were detected, least significant difference (LSD) procedures were used to compare cropping system effects. Trend analysis was used to partition main effects of N rate into linear, quadratic, and quadratic-plateau components. This latter form of regression analysis (SAS-NLIN procedure, SAS Institute, 1985) was chosen over quadratic regression when it resulted in a >10% reduction in residual error mean square and, at the same time, when it provided a better visual explanation of the data. Optimum N fertilizer requirements were represented by the lowest fertilizer N rate associated with highest yields of ripe fruit. Minimum N fertilizer requirements were associated with a ripe fruit yield of 50 t·ha−1, the industry standard for the minimum economical yield level (D. Scheirer, personal communication).

Results and Discussion

Cropping systems and their respective grain yields, along with the initial soil properties at the start of the pumpkin experiments in 1996 and 1998 are shown in Table 2. In general, cropping system grain yields were good in both years and were representative of commercial corn and soybean production in Illinois (Illinois Agronomy Handbook, 1992). Soil analyses (0–30 cm) at the beginning of each of the pumpkin experiments (prior to application of N treatments) showed that the initial amounts of soil organic matter and total N were unaffected by cropping system, averaging 31.3 and 1.69 g·kg−1, respectively in 1996, and 35.5 and 1.92 g·kg−1, respectively in 1998. Similarly, preplant soil NO3-N was not significantly influenced by cropping system; however, a trend occurred in both years (P = 0.15 in 1996; P = 0.08 in 1998) with NO3-N levels generally highest following soybean and lowest following 2-years corn.

Ripe fruit production. The number of ripe fruit produced in 1996 was not affected by cropping system or N fertilization rate, with pumpkins averaging almost 9500 ripe fruits/
ha (Table 3). Concomitantly, the mean fresh weight of ripe fruit was also unaffected by cropping system, but increased with increasing N rate up to 112 kg·ha⁻¹, where fruits averaged 6.2 kg each. Significant interactions between cropping system and N rate influenced ripe fruit yield in 1996, as the relative increase in total weight of ripe fruit to applied N was markedly greater following corn or 2-years corn than following soybeans or fallow ground (Table 4). Additionally, reductions of total weight of ripe fruit of ≈22% and 13% occurred at the high N rate following soybeans or fallow, respectively, but not following corn or 2-years corn. Overall, the response pattern of total weight of ripe fruit to applied N in 1996 was quadratic following either soybeans or fallow ground, and quadratic-plateau (leveling-off at the high N rate) following corn or 2-years corn. From the response functions generated from the data, highest total weight of ripe fruit was estimated at 67.3 t·ha⁻¹ with 161 kg·ha⁻¹ N following corn, 63.8 t·ha⁻¹ with 116 kg·ha⁻¹ N following soybeans, 62.1 t·ha⁻¹ with 205 kg·ha⁻¹ N after 2-years corn, and 60.8 t·ha⁻¹ with 139 kg·ha⁻¹ N following fallow ground (Table 5). Minimum N fertilizer requirements, associated with a ripe fruit weight of 50 t·ha⁻¹, were calculated at 33, 13, 66, and 30 kg·ha⁻¹ N in the respective cropping systems.

In 1998, the number and mean weight of ripe fruit were unaffected by cropping system or N fertilization rate, with pumpkins averaging 7860 ripe fruits/ha and 6.2 kg/fruit (Table 6). Similar to that in 1996, significant interactions between cropping system and N fertilization rate affected ripe yield in 1998, as the positive response in total ripe fruit weight to applied N was greater following corn or 2-years corn than following soybeans or fallow ground (Table 7). However, unlike in 1996, total weight of ripe fruit in 1998 decreased at the high N rate following soybeans or fallow ground (Table 7). Minimum N fertilizer requirements in 1998 were calculated at 56, 61, 72, and 63 kg·ha⁻¹ N, respectively.

Green fruit production. In 1996, the production of green fruit was relatively unaffected by cropping system or N fertilization rate (Table 3). The one exception to this response was lower total weight of green fruit following 2-years corn than in the other cropping systems. Averaged over N rates, green fruit accounted for about 21% of the total fruit weight produced following 2-years corn, compared to ≈24% in the other following systems.

In 1998, the number, total yield, and mean fresh weight of green fruit were significantly affected by both cropping system and N fertilization rate (Table 6). Total weight of green fruit was generally highest following soybeans.
fertilization rate in 1996, averaging 13,400 fruits/ha (Table 3). Similar to the response in ripe yield, significant interactions between cropping system and N fertilization rate affected total yield, as the response pattern of total fruit weight to increasing rates of applied 
N in 1996 was quadratic in pumpkins following either soybeans or fallow ground, and quadratic-plateau following corn or 2-years corn (Table 4). Maximum total fruit weight in 1996 was estimated at 84.1 t·ha⁻¹ with 154 kg·ha⁻¹ N following fallow, 81.4 t·ha⁻¹ with 120 kg·ha⁻¹ N following soybeans, 78.1 t·ha⁻¹ with 135 kg·ha⁻¹ N following fallow ground, and 77.0 t·ha⁻¹ with 225 kg·ha⁻¹ N after 2-years corn (Table 5).

In 1998, total fruit number was unaffected by cropping system, but increased with increasing N fertilization rate up to N at 168 kg·ha⁻¹ (Table 6). Unlike in 1996, total fruit weight in 1998 was not influenced by significant interactions between cropping system and N rate. Averaged over cropping systems, total fruit weight showed a quadratic response to applied N, with maximum total yields estimated at 75.6 t·ha⁻¹ with 139 kg·ha⁻¹ N (Table 5).

Soil N₂O₅ and yield response relationships. The relationship between the percent response of total ripe fruit weight to N fertilization and residual soil N₂O₅-N levels was shown in Figure 1. Soil N₂O₅-N levels were used for this analysis because analytical methods for N₂O₅-N are relatively quick and simple when compared to total soil mineral NO₃-N (Mulvaney, 1996), and because soil N₂O₅-N can be highly reflective of previous cropping practices (Anderson et al., 1997; Porter and Sisson, 1991).

In seven of the plots (three following corn: four following 2-years corn), with preplant soil NO₃-N testing ≤5 mg·kg⁻¹, the relative increase in total ripe fruit weight to N fertilization was more than 75%. Conversely, in two of the plots (following fallow ground), the relative increase in total ripe fruit weight to N fertilization was small (<20%), even though soil NO₃-N levels were less than 10 mg·kg⁻¹. In several of the plots following soybeans, moderate to high levels of preplant soil NO₃-N (>10 mg·kg⁻¹) were associated with low response of ripe fruit weight to N fertilization. When the combined data for the 2 years were fit to a quadratic-plateau response model (r² = 0.50), total ripe fruit weight showed a positive response to N fertilization at soil NO₃-N levels <17.6 mg·kg⁻¹, and limited or no response to applied N if soil NO₃-N measured ≥17.6 mg·kg⁻¹. This value is in line with the critical levels of 15.9 mg·kg⁻¹ for preplant soil NO₃-N (Schmitt and Randall, 1994), and 21.0 mg·kg⁻¹ for presideded soil NO₃-N (Bundy and Andraski, 1993) reported for corn response to N fertilization on other medium- to fine-textured soils in the upper Midwest.

In total, these results demonstrate that fertilizer N requirements for pumpkins on loam soil will vary depending on cropping system, with N requirements increasing following corn or 2-years corn in the rotation, and decreasing following soybeans. Despite generally similar yields, the optimal N fertilization rate for highest total weight of ripe fruit following soybeans, for the two pumpkin studies, was estimated at 109 kg·ha⁻¹ N, compared to 128 kg·ha⁻¹ N following fallow ground, suggesting a soybean N-credit of around 19 kg·ha⁻¹ N. In contrast, the optimal N fertilization rate for highest total weight of ripe fruit following corn or 2-years corn averaged 151 and 178 kg·ha⁻¹, respectively, indicating a negative rotation effect on pumpkin N requirements of 23 kg·ha⁻¹ N following corn and 50 kg·ha⁻¹ N following 2-years corn.

Current Univ. of Illinois fertilizer guidelines for pumpkins recommend 134 kg·ha⁻¹ N, plus a N-credit of 28 to 34 kg·ha⁻¹ N when following soybeans or other legumes (Gerber and Swiader, 1985). Based on these data, the above recommendations appear reasonably accurate for pumpkins following soybeans, but somewhat underrated following corn. Including 2-years corn in the rotation with pumpkin is likely to require high rates of N fertilizer (151–205 kg·ha⁻¹ N) when following soybeans or other legumes (Gerber and Swiader, 1985).
extendable to other pumpkin and winter squash types with similar N requirements.

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