Response of *Apios americana* to Nitrogen and Inoculation

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Abstract. *Apios americana* Medikus (apios) is a wild tuberous legume with potential as a crop plant. Five apios accessions were grown in sand culture in two greenhouse experiments to examine the effect of N fertilization and inoculation with *Bradyrhizobium japonicum* on yield and plant characteristics. A common soybean *B. japonicum* strain (USDA76) was applied to plants watered with 0, 50, 100, 200, or 300 ppm N solutions (NH_4NO_3), plus a complete nutrient solution. At 0 N, total dry matter yield of noninoculated plants was only $\approx 30\%$ of inoculated plants. However, total dry-matter yields of inoculated plants at 0 N were only $\approx 77\%$ of plants supplemented with 50 or 100 ppm, indicating that inoculation alone was insufficient to meet the N needs of the plant. Tuber weight was increased by both N and inoculation, but tuber weight decreased at N concentrations >100 ppm. Differences among plant accessions with regard to tuber fresh weight, harvest index, and modulation were found. These studies indicated that N fertilization maybe required to maximize tuber yields of apios.

Apios americana (groundnut or apios) is a wild legume native to the eastern half of North America that produces edible tubers, fleshy roots, and seeds. According to several records, the plant was gathered by various Native American tribes (Yarnell, 1964). It was consumed by the Pilgrims in their first years in America (Fernald and Kinsey, 1943) and probably brought to England as a New World potato by Sir Walter Raleigh (Schery, 1972). This history, in conjunction with its N-fixing capabilities and the high protein and available carbohydrate content of the tuber (Walter et al., 1986; Wilson et al., 1987), has led to interest in apios as a possible new crop (Blackmon and Reynolds, 1986; Duke, 1987; Reed and Blackmon, 1985; Reynolds, et al., 1990; Vietmeyer, 1986). Several wild-plant food enthusiasts have indicated a taste preference for apios over domesticated potato (*Solanum tuberosum* L.) (Gibbons, 1974; Harris, 1968; Medsger, 1939).

One of the reasons for interest in apios is

its unique role as an N_2 -fixing and tuber-producing plant (Putnam et al., 1990). Most tuber or root crops, such as potato, yam (*Dioscorea* sp.), or sweetpotato (*Ipomoea batatas* L. Lam.), require large inputs of N fertilizers for maximum economic yields. The introduction of a tuberous crop that fixes atmospheric N_2 might reduce or eliminate this requirement. However, to our knowledge, there is no published information as to whether *Rhizobium* symbiosis is sufficient to supply the N needs of apios plants. Greenhouse studies were initiated to assess the importance of inoculation and additions of mineral N to plant growth, tuber yield, and nodulation of *A. americana*.

Greenhouse experiments were conducted using seed harvested from wild plants grown in Louisiana and North Carolina. The accession numbers and location of origin are provided in Table 2. Accessions chosen in the 2nd year differed slightly because of their potentially better adaptation to Minnesota. Accession 5 was added in 1988, and accessions 2 and 3 had insufficient seed for further experimentation in 1988. Sand was sterilized and placed in 5.8-liter pots, and surface-sterilized seed was planted in a randomized complete-block design with four replications. The trials were initiated on 3 Mar. 1987 (1987 experiment) and 12 Oct. 1987 (1988 experiment). The inoculated treatments received 10^7 cells per plant of a *Bradyrhizobium japonicum* soybean strain, USDA 76, delivered on a peat base. After emergence, the sand was covered with 2 cm of perlite to reduce the opportunity for rhizobial cross-contamination and pots were separated by 30 cm. Nitrogen (in the form of NH_4NO_3) at 0, 100, and 300 ppm N in 1987 and 0, 50, 100, and 200 ppm N in 1988 was applied twice weekly through plastic access tubes. A Hoagland's complete nutrient solution (without N), balanced to a pH of 6.8, was

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Table 1. Plant characteristics² of apios as affected by Nodes/plant inoculation and nitrogen (1988).

N (ppm)	Tuber		Harvest index ^y (%)	Plant ht (cm)	Nodes/ plant	Vigor (rating) ^x	Color (rating) ^w	Leaf length ^v (mm)
	Fresh wt (g/plant)	No./plant						
Noninoculated								
0	11.4	2.8	35.5	69	13.0	1.7	1.7	32
50	44.7	10.1	44.3	127	19.5	3.8	3.8	39
100	35.5	10.8	37.9	118	18.6	3.6	3.6	40
200	25.7	3.8	35.2	88	17.5	3.1	3.7	37
Inoculated								
0	21.2	9.9	22.3	122	18.2	3.6	3.9	46
50	31.2	8.7	24.3	129	20.0	4.3	4.6	43
100	27.2	7.7	21.8	137	20.4	4.2	4.6	41
200	29.0	6.9	30.8	89	16.8	3.0	3.7	42
Sources of variation								
Nitrogen (N)	**	NS	NS	**	**	**	**	NS
N linear	NS	NS	NS	NS	NS	NS	**	NS
N quadratic	**	**	NS	**	**	**	**	NS
N cubic	*	NS	NS	NS	NS	NS	NS	NS
Access. (A)	**	**	**	**	**	**	**	**
N × A	NS	NS	*	NS	*	NS	NS	*
Inoc. (I)	NS	NS	**	*	*	**	**	**
N × I	*	*	NS	NS	*	**	**	**
A × I	NS	NS	NS	NS	NS	NS	NS	NS
N × A × I	*	NS	*	NS	NS	NS	NS	NS

²Mean of three accessions grown in 1988.^yTuber dry weight as a percentage of total dry weight.^x1-5 scale, 5 = most vigorous.^w1-5 scale, 5 = darkest green.^vLeaf blade plus petiole.NS,*,**Nonsignificant or significant at $P < 0.05$ or < 0.01 , respectively, by ANOVA. Fig. 1. Dry matter yield of *A. americana* in response to inoculation and application of NH_4NO_3 in 1987 (mean of four accessions). I = inoculated, NI = noninoculated control. (Significant effects at $P < 0.05$: Nitrogen, Inoculation, $\text{N} \times \text{I}$.)

also applied twice weekly through access tubes. Pots were leached to prevent salt accumulation. Supplemental fluorescent lighting was provided at a quantum flux density of $\approx 500 \mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ during an 18/6 h light/dark cycle. The vines were trained on bamboo stakes. Plants were harvested on 5 Aug. 1987 and 7 June 1988, for the 1987 and 1988 experiments, respectively.

Data collected 2 weeks before harvest included plant height, vigor of shoots, color of plants, and number of shoots. At harvest, number of tubers, weight of tubers, root weight, viable nodule weight and number, and dry weight of herbage were recorded. Occasionally, fleshy roots were produced by plants, and these were included as tubers. Analysis of variance was applied to the data. The sums of squares for N were partitioned into orthogonal contrasts of linear, quadratic, and cubic effects. A Fisher's (pro-

tected) least significant difference was used to separate accession means (Steel and Torrie, 1980).

Plant growth and total yield of noninoculated *A. americana* plants were $\approx 30\%$ of those of inoculated treatments at zero N (Figs. 1 and 2). However, inoculation alone was insufficient to maximize total plant weight or tuber yields in either study. Through symbiosis with *B. japonicum*, apios produced total dry matter yields $\approx 77\%$ of the yield from the optimum N plots (Figs. 1 and 2). Total plant and tuber dry matter yield increased with the addition of N. However, high amounts of N, particularly 200 ppm N (Fig. 2), decreased yield and plants showed symptoms of ammonium toxicity.

Tuber production was affected more than total dry matter yields by the addition of N. Fresh weight of tubers increased 21% and 47% (1987 and 1988, respectively) with ad-

ditions of 50 (1987) or 100 (1988) ppm N to the inoculated plants (Table 1). Data for 1987 were similar, but are not shown.

Noninoculated plants allocated $\approx 50\%$ more dry matter to tubers than to shoots than inoculated plants as indicated by a higher harvest index at zero N (Table 1). Additions of N did not affect the harvest index or change the difference between inoculated or noninoculated plants. These results indicate a differential allocation of carbon between the inoculated and noninoculated plants that was independent of exogenous N supply. The lower allocation to tubers in the inoculated plants may represent reallocation of carbohydrate towards N_2 -fixation in the nodule, but more detailed studies would have to be conducted to verify this supposition.

Combined tuber and root dry-matter yield of inoculated treatments was higher than that of noninoculated treatments at zero N (Figs. 1 and 2). Fresh weight tuber yields of inoculated plants at zero N were 86% greater than those of noninoculated plants (Table 1). However, this difference between inoculation treatments was not consistent in the N-treated pots. The difference between inoculated and noninoculated tuber yields, apparent at zero N in both years, was reversed at 50 or 100 ppm N in the 1988 study. The data indicated that for production of tubers, noninoculated plants were more responsive to additions of N than the inoculated plants.

The increase in tuber yield with 50 or 100 ppm added N was accompanied by increases in tuber count only for noninoculated plants (Table 1). Tuber count declined at high concentrations of N in the noninoculated treatments.

Plant height, node count, leaf length, color,

Table 2. Yield and characteristics of *Apios americana* accessions grown in 1987 and 1988.

Accession	Origin	Total dry wt		Tuber fresh wt		Harvest index ^y		Nodule fresh wt		Nodules/plant	
		1987	1988	1988	1988	1987	1988	1987	1988	1987	1988
		g/plant				mg/plant					
1. XXXVI E3	Pointe Coupee Parish, La.	43.4	41.4	23.0	38.7	14.2	30.7	2.7	2.6	40	57
2. X1 F1	Iberville Parish, La.	41.1	---	15.2	---	9.3	---	1.9	---	21	---
3. LXVIII EI	Iberville Parish, La.	50.4	---	13.8	---	9.2	---	2.6	---	27	---
4. XXXVII	Iberville Parish, La.	43.4	36.9	11.3	24.6	8.2	26.1	2.3	2.5	46	75
5. XIXA2	Pleasant Plain, N.C.	---	23.9	---	21.3	---	36.5	---	1.1	---	30
LSD ($P = 0.05$)		NS	3.5	3.9	4.6	2.5	5.2	NS	0.4	NS	14

^xMean of N treatments.^yTuber dry weight as a percentage of total dry weight.

Fig. 2. Dry matter yield of *A. americana* in response to inoculation and application of NH_4NO_3 in 1988 (mean of three accessions). I = inoculated, NI = noninoculated control. (Significant effects at $P < 0.05$; Nitrogen, Inoculation, variety, $N \times I$)

and vigor rating (Table 1) were increased by inoculation and by N in a pattern similar to total dry matter production (Fig. 2).

There were differences among accessions for tuber fresh weight, total dry weight, harvest index, and nodule fresh weight (Table 2). These apios accessions, obtained from the wild, generally exhibited a high degree of variability (Blackmon and Reynolds, 1986). However, the accession XXXVI E3 from Louisiana was more vigorous and produced a significantly greater fresh weight of tubers in both years than other accessions. Harvest index also tended to be high in this line. This line also performed well in field trials (Putnam et al., 1990).

If apios is grown in an agronomic or a horticultural setting it maybe planted by seed or by tuber. If tubers are used, rhizobial symbionts likely would accompany the clones, and if the tubers are stored at low temperatures, these *Rhizobium* may remain viable. Inoculation is likely to be more important in

seed-planted apios. However, the fact that apios was well nodulated with a common soybean strain in this study and that others have reported modulation with rhizobia obtained from cowpeas (Allen and Allen, 1981) suggests that under agronomic conditions, modulation should not be a severe problem. We have observed nodules on plants growing without any controlled inoculation in experimental plots and on plants collected from the wild in Minnesota.

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