Fertilizer N Use Efficiency and Associative N_2-Fixation of Sweet Potato

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ABSTRACT

Experiments evaluated potential mechanisms for minimizing fertilizer N requirements of sweet potato (Ipomoea batatas). The response of four sweet potato cultivars to drip 'fertigation' (DF), drip irrigation + granular N (DI) and nonirrigation + granular N (NI) were compared. Method of N application significantly influenced yield, dry matter and N recovery.

Isotopically labeled fertilizer at 18 kg N/ha was applied to 'Jewel' sweet potato at 3-week intervals for 15 weeks. Three weeks after each application, roots and foliage were analyzed for fertilizer N recovered. Fertilizer N recovered in foliage and storage roots was greatest when applied at 6 and 12 weeks after transplanting respectively.

Nitrogenous activity of fibrous roots from six sweet potato cultivars was determined with acetylene reduction assay. Nitrogenous activity of fibrous roots ranged from 66 to 465 nmoles C_2H_4/h/g depending on the cultivar. Sixteen N_2-fixing bacterial isolates with morphological characteristics similar to Azospirillum were isolated in vitro. Nitrogenase activities of single colonies ranged from 32 to 472 nmoles C_2H_4 per culture-h.

The recommended rate of fertilizer N for optimum production of sweet potato ranges worldwide from 0 to 146 kg N/ha and depends on soil type, variety, climate, cropping system, product use and availability of fertilizer (Hill, 1982). Time and method of fertilizer N application influence yield, N uptake and quality of sweet potatoes (Alexander et al., 1976; Hammet, 1981; Miller and Covington, 1982) and may influence fertilizer N use efficiency. The fact that only 38% to 50% and 30% to 80% of applied fertilizer N is recovered by sweet potato and other annual crops, respectively, indicates a need to increase fertilizer nitrogen use efficiency in crop production (Hill, 1982; Hauck, 1978; Tucker and Hauck, 1978). Part of the reason for the low fertilizer nitrogen recovery can be attributed to leaching, denitrification, volatilization and immobilization. In 1980, these processes resulted in an estimated loss of 13-35 million metric tons of applied fertilizer throughout the world (Harris and Harre, 1979).

Through sweet potato is drought tolerant, if supplemented by irrigation, yield can be increased (Constantine et al., 1974). Drip irrigation is known for its high water efficiency and it provides a ready source of soil moisture to the 'root sorption zone.' Drip irrigation can supply plants with nutrients

(drip 'fertigation') such as nitrogen, in controlled amounts during the growing season (Bresler, 1977; Jammis, 1980).

An alternate approach to reducing fertilizer nitrogen requirement is to develop plant-bacterial associations that result in biological nitrogen fixation of non-legumes (Neyra and Dobereiner, 1977; van Berkum and Bohlool, 1980).

The objectives of this study were to: evaluate the effect of drip 'fertigation' on yield and N uptake of sweet potato; determine the effect of time of N-15 depleted fertilizer N application on the uptake and distribution of N in sweet potato; and evaluate biological N_2-fixation associated with sweet potato roots.

Materials and Methods

Drip 'Fertigation' Study

Sweet potato slips of four cultivars ('Jewel', 'Carver', Centennial' and 'Rojo Blanco') were transplanted on May 28, 1981, into Norfolk sandy loam; rows were 1.2 m wide and 4.2 m long. Treatments were drip irrigation + granular N (DI); drip 'fertigation' (DF); and, nonirrigation + granular N (NI). Fertilizer nitrogen was ammonium nitrate (NH_4NO_3) applied at 90 kg/ha. For the DI and NI treatments fertilizer N was split applied: half before transplanting and half 6 weeks after. The DF treatment consisted of five applications of fertilizer N applied at 18 kg/ha every 3 weeks through the drip lines. Phosphorus and potassium were applied, based on soil test, by broadcast and incorporation prior to transplanting. The experimental design was a randomized complete block with irrigation treatments as blocks and four replications of each cultivar in each block.

Sweet potato roots and foliage were harvested on October 22, 1981, graded, and analyzed for percent dry matter, and total N content (Bremner, 1965).

Depleted N-15 Uptake Study

'Jewel' sweet potato slips were transplanted on May 28, 1981, into rows 1.2 m wide and 4.2 m long. Each row represented a different treatment and was replicated three times. The treatments were the times/date of N-15 depleted ammonium nitrate application. Figure 1 shows times/dates of application of labeled and unlabeled ammonium nitrate. Times coded with "X" and without "X" indicate N-15 labeled and unlabeled ammonium nitrate, respectively. At each application time, 18 kg N/ha was dissolved in 23.4 liters of water and 0.6 liters of this solution was injected into the 'root sorption zone' of each plant in the designated rows. The experimental design was a randomized complete block design with three replications.

Three weeks after each application of fertilizer N, two plants from the exterior end of each row were sampled by digging the entire plant. Plants were washed, air dried and separated into leaves, stems, and roots. Storage roots were distinguished from fibrous roots by color and size. Total N was determined and isotope ratio analysis was carried out by mass spectrometry (Bremner, 1965).

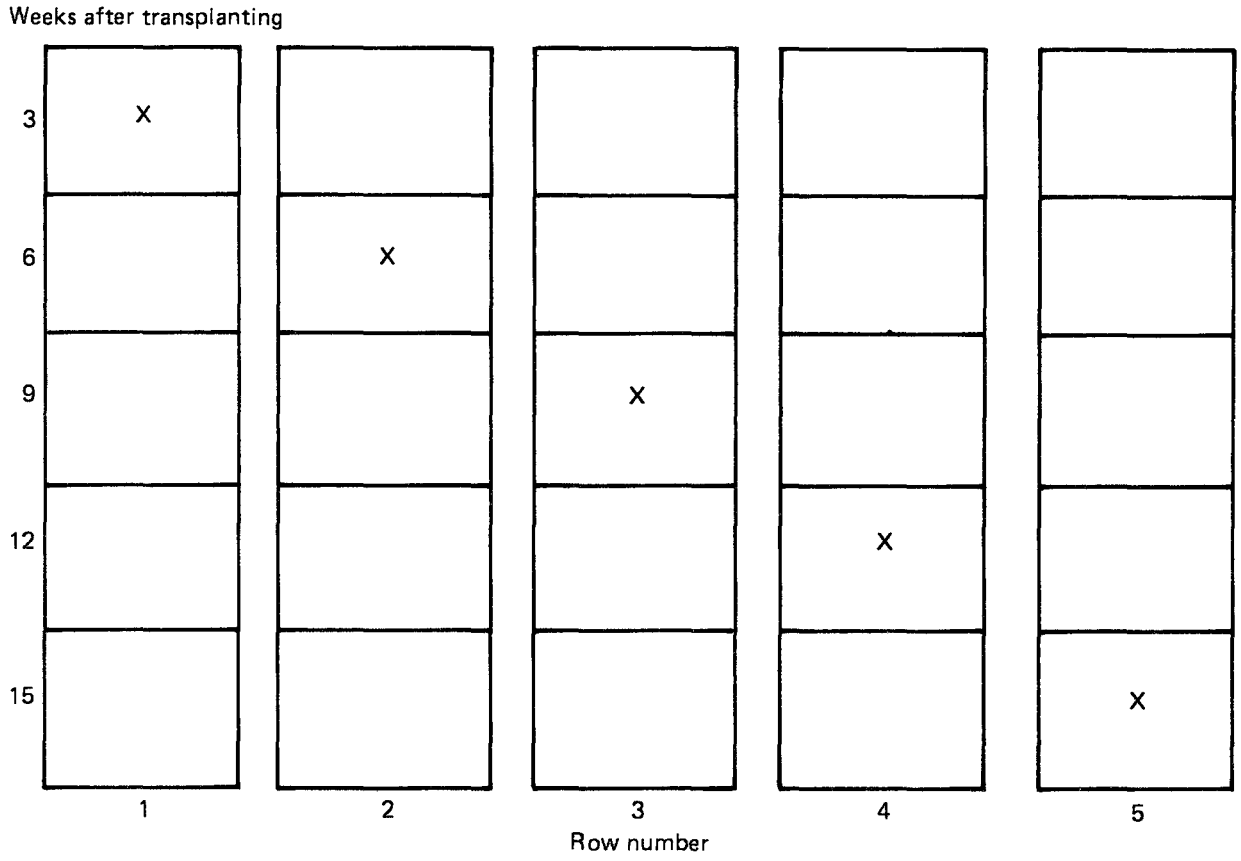

Figure 1. Time of application of N-15 depleted fertilizer N.

Associative N_2-Fixation Potential

A greenhouse experiment was conducted with six sweet potato cultivars ('Jewel', 'Rojo Blanco', 'Southern Queen', 'Haymen Yam', 'Centennial' and 'Carver'). Cuttings of the six cultivars were placed into 10x10 cm and 20x20 cm black plastic pots containing Norfolk sandy loam in a complete randomized design with three replications. After growth for 3 months, soil was taken from the roots and placed into 500 ml Mason jars with rubber ports. Nitrogenase activities of roots were determined using the acetylene reduction assay (van Berkum, 1980).

Washed roots (5 mm in length) were incubated in nitrogen free semisolid malate medium (Dobereiner, 1980). Cultures that yielded greater than 30 nmoles C_2H_4 reduction per culture-h were identified as positive. Serial dilutions were

made onto semisolid medium and microscopic examination used to verify the presence of Azospirillum.

Results and Discussion

Table 1 shows the influence of drip irrigation and fertilizer N application method on yield of sweet potato grades. US #1's and canners tended to be higher for DF and NI than DI. Jumbos and marketable yields were significantly higher for DF and NI than DI. Cracks and nonmarketable yields were significantly higher for DF and DI than NI. Total yields were 25% higher with DF than DI or NI though the difference was not significant at the 5% level. These results show that DI was inferior to DF and NI in production of marketable sweet potatoes. DF was the best method for obtaining optimum yield production, if nonmarketable grades of sweet potatoes are used to produce ethanol for gasohol production or as a supplement in animal rations.

Table 1. Effect of drip irrigation and fertilizer N application method on sweet potato grade categories (US #1's, canners, jumbos, culls and cracks) and total yield.

Grade	DF (kg/ha)	DI (kg/ha)	DI (kg/ha)
US $1's	7,084 a*	5,402 a	6,627 a
Canners	2,772 a	1,743 a	1,839 a
Jumbos	3,545 a	1,281 b	5,064 a
Culls	817 a	1,403 a	1,069 a
Cracks	6,250 b	6,696 b	2,166 a
Total marketable	13,401 a	8,426 b	13,531 a
Nonmarketable	7,067 b	8,099 b	3,235 a
Total	20,468 a	16,525 a	16,166 a

*Mean separation within rows using Duncan's multiple range test, 5% level.

Data in Table 2 show the effect of drip irrigation and fertilizer N application method on percent dry matter, total N and percent protein of sweet potato. The percent dry matter was higher for NI than DI, and was lowest for DF. These results were similar to those found by Constantine et al., (1974) using sprinkler irrigation. Since the percent dry matter is directly related to storageability, roots grown with DF would be expected to have better storageability than with DI, and poorer storageability than with NI.

A significantly lower ($P < .05$) foliage dry weight was produced with DF than with DI. There was a tendency for lower foliage dry weight with NI than DI. The results in Tables 1 and 2 indicate an inverse relationship between foliage dry weight and marketable yield of sweet potato. The DI treatment apparently increased foliage growth at the expense of marketable roots, when compared to the DF and NI treatments. DF had a significantly lower percentage of protein in roots and foliage and lower total N in foliage compared to DI. The lower N recovery explains the significantly lower foliage growth with DF than DI and possibly resulted from lower N availability and uptake during maximum growth of the foliage. Protein content in roots was highest with NI and highest in foliage with

DI. These findings may prove important if present studies of sweet potato foliage as a vegetable source indicates that protein content influences marketability. Cultivar comparisons (data not shown) indicate that DF may be a beneficial cultural practice for increasing total yields of 'Jewel', 'Rojo Blanco' and 'Centennial' but not of 'Carver'.

Table 2. Effect of drip irrigation and fertilizer N application method on dry matter, % dry matter, total N and % protein of sweet potato.

	DF	DI	NI
% Dry matter	32.1 b*	30.8 a	32.6 c
Foliage dry matter	2,788 a	4,337 b	3,459 ab
Total N/ha			
Roots	26.0 a	31.2 a	46.0 b
Foliage	31.0 a	47.7 b	57.4 b
% Protein			
Roots	2.6 a	3.9 b	5.2 c
Foliage	6.9 a	9.8 b	7.4 a

*Mean separation within rows using Duncan's multiple range test, 5% level.

Percent labeled N recovered by sweet potato foliage and roots at different times showed highest nitrogen recovery occurred when nitrogen was applied at 6 and 12 weeks after transplanting for foliage and roots, respectively. There was a substantial decrease in percent fertilizer N recovered in foliage for N applied at 9 to 12 weeks after transplanting, while nitrogen recovered in storage roots increased during this period. The decrease in N recovered in leaves and fairly uniform recovery in storage roots after 9 weeks most likely is related to the fact that storage root initiation begins roughly 9 weeks after transplanting for many sweet potato cultivars (Onwueme, 1978) and once initiation begins the storage roots become the major sink for nutrients.

The percent labeled N recovered from N applied at 12 and 15 weeks decreased in leaves, tended to level off in fibrous and storage roots, and tended to increase in stems. The latter result most probably occurred because stems can act as an intermediate sink for temporary storage of nutrients required in other plant parts during periods of stress or maximum demand. Greatest percent of labeled N (29%) recovered by roots plus foliage occurred for N applied at 6 weeks after transplanting. These results suggest that sweet potato utilizes most of the fertilizer N when applied between 3 and 9 weeks after transplanting.

The rates of nitrogenase activity of fibrous roots of five sweet potato cultivars are in Table 4. Rates range from 66-465 nmoles C_2H_4/h per g dry root depending on cultivar and pot size used to measure the rate of acetylene reduction. The rates of acetylene reduction are comparable to results reported from grasses. Endogenous ethylene production and ethylene oxidation by excised roots were found to be negligible.

Table 3. Storage root weight and nitrogenase activity of excised fibrous roots of six sweet potato cultivars grown in 10x10 vs 20x20 cm pots. The rate of acetylene reduction was determined from gas samples taken at 1-8 h after injection of acetylene. The results are means of three replications ± standard error.

	10x10 cm pots		20x20 cm pots	
Cultivar	Nitrogenase activity nmoles C_2H_4/g dry root-h	Fresh weight of storage root (g)	Nitrogenase activity nmoles C_2H_4/g dry root-h	Fresh weight of storage root (g)
Carver	287 ± 44	4.2 ± 1.1	465 ± 290	15.5 ± 7.2
Jewel	185 ± 0	0.0 ± 0.0	322 ± 0	6.2 ± 2.6
Centennial	71 ± 12	0.0 ± 0.0	68 ± 25	21.3 ± 7.0
Rojo Blanco	155 ± 10	7.2 ± 1.2	86 ± 10	66.1 ± 9.1
Haymen Yam	311 ± 55	8.2 ± 2.8	426 ± 146	25.0 ± 11.2
Southern Queen	205 ± 53	4.7 ± 4.7	66 ± 11	34.7 ± 3.7

Table 4. Acetylene reduction of N_2 fixing isolates from five sweet potato varieties.

Variety Isolates	nmoles C_2H_4 per culture-h ± S. E.
Jewel	
TI-sp-1	137 ± 17
TI-sp-2	32 ± 2
TI-sp-3	191 ± 49
Centennial	
TI-sp-4	44 ± 18
TI-sp-5	309 ± 120
TI-sp-6	198 ± 128
*TI-sp-16	472 ± 232
Rojo Blanco	
TI-sp-7	146 ± 8
TI-sp-8	274 ± 189
TI-sp-9	214 ± 8
TI-sp-10	66 ± 40
Southern Queen	
TI-sp-11	231 ± 42
TI-sp-12	94 ± 52
TI-sp-13	163 ± 60
Carver	
TI-sp-14	180 ± 8
TI-sp-15	403 ± 43

*TI-sp-16 was isolated from the skin of the storage root. All other isolates were from fibrous roots.

All enrichment cultures contained dense white pellicles 1 mm below the N-free malate medium surface, which is a characteristic of Azospirillum. Microscopic examination of pure cultures revealed organisms similar in morphology and motility to Azospirillum spp. (Tarrand et al., 1978). Nitrogenase activity of isolates ranged from 32 to 472 nmoles C_2H_4 per culture-h (Table 4). TI-sp-15, TI-sp-5 and TI-sp-8 resulted in highest nitrogenase activities. Biochemical characterization of the 16 isolates (Hill et al., 1983) suggests that A. brasilense and A. lipoferum associate with sweet potato roots. These results and work by others (Cohen et al., 1980; Dobereiner, 1978) suggest that associative N_2-fixation of sweet potato be further explored.

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