NITROGEN FERTILIZER EFFICIENCIES ON POTATOES[1]

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Abstract

Nitrogen fertilizer efficiencies must be known to successfully apply N fertilizer according to crop growth needs. The objective of this study was to determine the recovery, partitioning, and translocation of N fertilizer applied at different times for potato production. Russet Burbank potatoes were fertilized preplant with ^{15}N-depleted ammonium sulfate, and during early and late tuber growth with urea containing $K^{15}NO_3$ in 1978 or $(^{15}NH_2)_2CO$ in 1980. All N applications increased tuber yields above the control treatments. The N recovery efficiency was 60% for the preplant N application, and over 80% and near 60% for the N applications during tuber growth in 1978 and 1980, respectively. Good agreement was found between the isotope and difference methods of determining N recovery efficiencies. Labeled N was initially concentrated in the stems and leaves, particularly if applied during tuber growth. Over 80% of the assimilated, labeled nitrogen was found in the tubers at the start of plant maturation. These data indicate that a significant improvement in N fertilizer efficiency would result from split N fertilizer applications made according to crop growth needs.

Compendio

Para una aplicación exitosa del fertilizante nitrogenado se debe conocer la eficacia del mismo, de acuerdo con las necesidades de crecimiento del cultivo. El objectivo de este estudio fue determinar la recuperación, división, y transporte del fertilizante nitrogenado aplicado en diferentes periodos en la producción de papas. Se fertilizaron papas del cultivar Russet Burbank con sulfato de amonio carente de ^{15}N, antes de la siembra, y con úrea conteniendo $K^{15}NO_3$ durante el crecimiento inicial y final de los tuberculos en 1978 o con $(^{15}NH_2)_2CO$ en 1980. Todas las aplicaciones de N incrementaron

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Accepted for publication March 21, 1988.

ADDITIONAL KEY WORDS: Recovery, partitioning, timing, preplant, seasonal, fertigation, petioles, *Solanum tuberosum*, translocation.

los rendimientos en tubérculos por encima de aquellos en los tratamientos testigo. La eficacia en la recuperación del N fue 60% para la aplicación de N anterior a la siembra, y más de 80% y cerca de 60% para las aplicaciones de N durante el crecimiento de los tubérculos, en 1978 y 1980, respectivamente. Se consideró que la eficacia más baja en 1980 fue causada por una deficiencia de P al final de la temporada. Se encontró buena relación entre el método del isótopo y el de las diferencias, para la determinación de la eficacia en la recuperación del N. El N marcado se concentró inicialmente en los tallos y hojas, principalmente cuando fue aplicado durante el crecimiento del tubérculo. Se econtró en los tubérculos más de 80% del nitrógeno marcado asimilado al inicio de la maduración de las plantas. Estos datos indican que una mejora significativa tendría lugar en la eficacia del fertilizante al dividir las aplicaciones del fertilizante nitrogenado efectuadas de acuerdo con las necesidades de crecimiento del cultivo.

Introduction

Traditionally, the potato crop's N requirement is all applied preplant or at the time of planting; however, many growers are now applying a portion of the N requirement during crop growth in the irrigation water. A low preplant N application with supplemental N applications during tuber growth has the potential to increase fertilizer N efficiencies and promote early tuber growth (5). Fertilizer use efficiency increased 35% from frequent N fertilizations compared with conventional fertilization practices on a loamy sand in Wisconsin (12), while daily N applications on a sandy soil in Washington had N fertilizer use efficiencies of 90% and 78% for adequate and deficient application rates, respectively (7). In contrast, N side-dressed at planting on a fine sandy loam in California had a recovery efficiency of 57% (14).

Crop recovery of fertilizer N is generally low (8). Much of this non-recovered fertilizer N is lost from denitrification, immobilization, or by leaching out of the root zone to eventually reach the ground water (6). A knowledge of the residual soil N, rate, and amount of N mineralized from soil organic sources in the root zone, and individual crop growth requirements are needed to optimize N fertilizer recommendations. A recent study reported the potato crop's N needs and provided diagnostic guidelines to schedule N fertilizer applications during crop growth (16). The N fertilizer recovery efficiencies for different application times must also be known to successfully fertilize during crop growth and development.

The overall research objectives were to study the effect of N availabilities on potato plant growth characteristics and to develop techniques for making N fertilizer recommendations according to stage and rate of crop growth. The plant N content, and the partitioning and translocation of N applied at different times for potato production are reported here.

Methods and Materials

All data were obtained from two experimental field studies near Kimberly, Idaho, in 1978 and 1980. Russet Burbank potato seed pieces (0.06 kg) were planted 0.2 m deep and 0.23 m apart in 0.91 m rows between 20 and 25 April on a Portneuf silt loam soil (coarse-silty, mixed, mesic Durixerollic Calciorthids). This soil has a calcic layer beginning at about 0.4 m that restricts root penetration but not water movement. The experiments followed cereal grains in the rotation to ensure a relatively low residual soil N content. Individual plots were six rows wide by 15 m long. A randomized complete block design was used with three or four replications.

A soil sample of several combined cores (0 to 0.46-m) was taken from each replication for NO_3-N analysis before any preplant fertilization (9), and an incubation estimate (3) of N mineralized from soil organic N sources. (Table 1). Soil NO_3-N concentrations in the surface 0.46-m soil layer in each treatment were also measured at each whole plant sampling in 0.02-m diameter soil cores combined across replications.

All preplant fertilizers were broadcast and incorporated 0.15-m into the soil. Preplant P, K, and micronutrient applications were based on University of Idaho soil test recommendations (10). Preplant N for 1978 and 1980 was applied as ^{15}N-depleted $(NH_4)_2SO_4$ (0.0199 atom percent ^{15}N), and NH_4NO_3, respectively; seasonal N applications were broadcast on the surface as urea immediately before an irrigation (Table 1). In 1978, $K^{15}NO_3$ (83.89 atom percent ^{15}N) was added to the urea, giving 4.233 and 3.788 atom percent excess ^{15}N for the 21 June and 2 August N applications, respectively. Two different replications were used for each labeled N application

TABLE 1. — *Nitrogen treatments and pretreatment soil analysis for N.*

Year-treatment	N applications: Total	Preplant	Seasonal (day/month)	Pretreatment: Residual NO_3-N	Mineralizable N[1]
	kg ha^{-1}			mg kg^{-1}	
1978-1	0	0	0	5	15
1978-2	134	134[2]	0		
1978-3	135	0	45 (21 June[3], 14 July, 2 August[3])		
1980-1	162	162	0	4	30
1980-2	342	162	45 (4 July, 18 July, 30 July, 11 August[4])		

[1]N mineralized at 30 C for three weeks (3).
[2]All applied as ^{15}N-depleted $(NH_4)_2SO_4$.
[3]Urea with $K^{15}NO_3$ added on 21 June and 2 August.
[4]Urea with $(^{15}NH_2)_2CO$ added on 11 August.

in 1978. Labeled urea (77.6 atom percent ^{15}N) was added to the urea fertilizer to give 3.215 atom percent excess ^{15}N in the 11 August 1980 N application. Additional N treatments in these experiments were discussed previously (16).

Both experiments were sprinkler-irrigated with a 15- by 12-m sprinkler head spacing when the plant-available soil moisture in the root zone dropped between 50 and 60%. Soil moisture was monitored with tensiometers placed in the row at the seed-piece depth (0.2 m). Each irrigation brought the soil moisture back to near the field capacity. Aldicarb (2-methyl-2[methythio] propionaldehyde 0-[methylcarbamoyl] oxime) insecticide and metribuzin (4-amino-6-1[1,1-dimethylethyl]-methylthio-1, 2, 4-triazine-5[4H]) herbicide were used in both experiments at 3.3 kg ha^{-1} (a.i.) and 0.8 kg ha^{-1} (a.i.), respectively.

Whole plant samples (a 1.5-m row segment) were taken from each plot at selected intervals from mid-tuberization to vine-kill. Plants were separated into stems, roots, tubers, active and inactive leaves. Active leaves are defined as those showing no visible signs of senescence. Roots and tubers were washed. All plant tissues were dried at 60 C, weighed for dry matter determination, ground to pass a 40-mesh screen, and analyzed for total N, including NO_3-N (2). The plant N was also analyzed for atom percent ^{15}N with an AEI MS-20 isotope-ratio mass spectrometer using conversion techniques (11). The percentage of N fertilizer recovered in each plant part from the ^{15}N-depleted $(NH_4)_2SO_4$ was calculated from the equation, $(100[N_T][a-b]/N_f[a-c])$, where N_T is the N content of the fertilized plant parts, N_f is the amount of ^{15}N-depleted fertilizer added, *a* and *b* are the atom percent ^{15}N of the plant parts grown on the nonfertilized and fertilized soil, and *c* is the atom percent ^{15}N of the ^{15}N-depleted fertilizer, respectively. The fertilizer ^{15}N recovered in the plant parts from the enriched treatments was calculated from the equation, $(N_T[a-b]/[c-b])$, where N_T is the N content of the plant part, *a* and *b* are the atom percent ^{15}N of the treated and non-treated plant parts, and *c* is the atom percent ^{15}N of the added N material (4). A composite sample of 30 to 40 petioles from the fourth leaf down from the growing tip was also taken from each plot at the same time as the whole plant samples. They were dried, ground, and analyzed for NO_3-N concentrations (9).

All remaining plant tops were removed in late September in preparation for final harvest. Tubers were mechanically harvested from two non-border rows each 9 or 12 m long from the center of each plot during the first week of October. Total tuber yields, the yields of graded tubers (1), and the specific gravity of about 4 kg of USDA #1 tubers were determined immediately after harvest.

Statistical analysis of variance was carried out using a randomized complete block design with the appropriate replications for each data set. Duncan's Multiple Range Test was used to make comparisons among treatment means.

Results

The total tuber yields were increased by N fertilization in both experiments (Table 2). No apparent yield differences occurred between the preplant N and the seasonal N treatments in 1978 (2 vs. 3), but there was a significant specific gravity reduction in the seasonal N treatment. Seasonal N applications, in addition to preplant N, did significantly increase total tuber yields in 1980 (1 vs. 2).

TABLE 2. — *Effect of N treatment on final tuber yields, size distribution, and specific gravity.*

Year-treatment[1]	Total final tuber yields[2]	USDA tuber grades[2] #1	#2	>0.28 kg	Tuber specific gravity[2]
	$Mg\ ha^{-1}$	%			
1978-1	32.6a	52.2a	6.6a	7.0a	1.087a
1978-2	45.0b	66.5b	3.1a	4.2a	1.085a
1978-3	46.8b	71.0b	7.0a	10.4a	1.082b
1980-1	46.6a	77.7a	18.0a	52.2a	1.080a
1980-2	52.0b	80.6a	13.4a	55.6a	1.078a

[1]See Table 1 for treatment descriptions.
[2]Treatment means within a year and category followed by the same letter are not significantly different at the 5% probability level according to the Duncan's multiple range test.

Nitrogen fertilization significantly increased whole plant N uptake over the control treament in 1978 (Figure 1). The N uptake for the preplant N treatment was also significantly larger than that for the seasonal N treatment at early samplings (30 June and 10 July). This was reversed at later samplings (21 August and 5 September). Nitrogen uptake for treatment 2 was significantly larger than treatment 1 for all samplings in 1980. The N uptake was generally larger in 1980 than 1978, reflecting the higher N fertilization rates and mineralized N (Table 1). The N uptake in the plants did not change appreciably after 1 August for the control and preplant treatments, but continued to increase in the 1978 seasonal N treatment (Figure 1).

The percentage of N fertilizer recovered by the plants in the preplant N treatment increased from about 30% at the first sampling (19 June) to slightly more than 60% for the last three samplings (Figure 2A). The percentage recovery of the ^{15}N applied 21 June rapidly increased to about 85% by 10 July (Figure 2B), while the recovery of ^{15}N applied 2 August approached 80% by the last sampling (Figure 2C). Recoveries of the ^{15}N applied on 11 August 1980 were about 60% by the last sampling (Figure 2C). The distribution of the 11 August 1980 ^{15}N in the plant parts was similar to the 2 August 1978 application, but proportionally lower (data not shown).

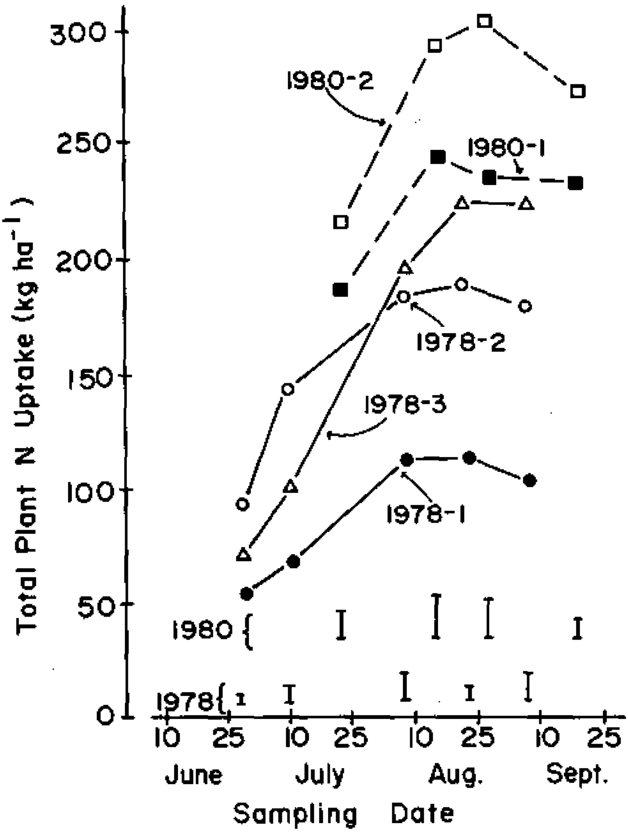

FIG. 1. The effect of N treatment and year on N uptake of whole potato plants. The vertical lines represent the standard error of the means within a sampling date and year.

The largest portion of the plant-assimilated ^{15}N was found in the vegetative portions at the early samplings. Most of this N appeared to be translocated to the tubers during the remainder of the growing season. Approximately 88%, 88%, 84%, and 84% of the recovered fertilizer N was found in the tubers in September for the 1978 preplant, 21 June 1978, 2 August 1978, and 11 August 1980 applications, respectively.

Petiole NO_3-N concentrations dropped rapidly after early tuber set (≈ 20 June) for the control and preplant N treatments (Figure 3). The 1978 seasonal N treatment (#3) maintained petiole NO_3-N concentrations between 6-10,000 mg kg^{-1}, while the combined preplant and seasonal N treatment (#2) in 1980 kept the petiole NO_3-N concentration above 17,000 mg kg^{-1}.

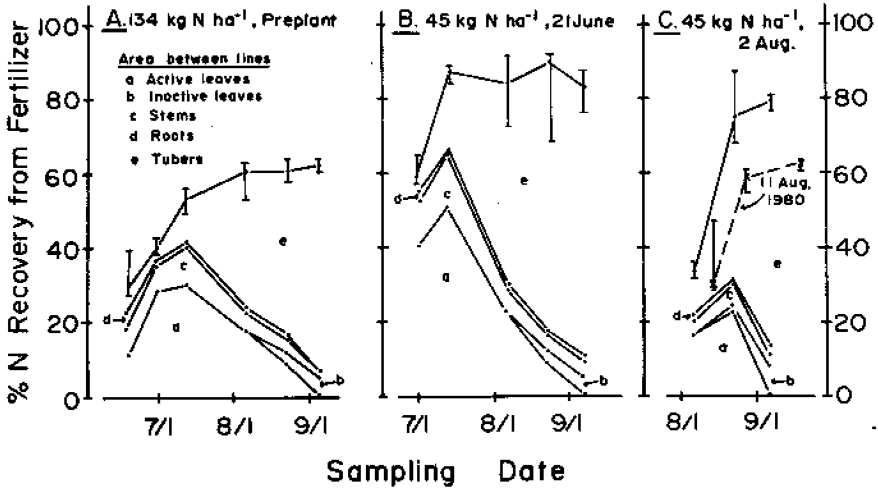

FIG. 2. The percentage of ^{15}N recovered in the different parts for the 1978 N fertilizer treatments; A. 134 kg N ha^{-1} applied preplant; B. 45 kg N ha^{-1} applied 21 June; C. 45 kg N ha^{-1} applied 2 August (dashed line is the total recovery for the 11 August 1980 ^{15}N treatment). Vertical bars represent the standard deviation for total plant recovery for that N treatment and sampling date.

Soil NO_3-N concentrations were also less than 5.0 mg kg^{-1} by 1 August in all N treatments except for 10 mg kg^{-1} in the1980-2 treatment (data not shown).

Discussion

Nitrogen applied seasonally in 1978 had a higher plant recovery percentage than preplant applied N. The seasonal N (urea) in 1978 was enriched by $K^{15}NO_3$ which may have exaggerated the N fertilizer recoveries. The apparent N fertilizer recovery was calculated by $(N_i\text{-}N_c)100/N_f$, where N_i and N_f is the N uptake by the plants and N fertilizer applied for the N treatment, and N_c is the N uptake by the plants on the control treatment, respectively. These calculations showed that the apparent recovery of N fertilizer for the 1978-2 preplant N treatment approached 60%, while the apparent recovery for the 1978-3 seasonal N treatment increased from about 40% to greater than 80% for the last two samplings. The apparent recovery for the 1980-2 seasonal N treatment was about 50%. In general, these data closely agreed with the ^{15}N data. Similar agreement between ^{15}N data and apparent N fertilizer recoveries are reported for N banded at planting (14).

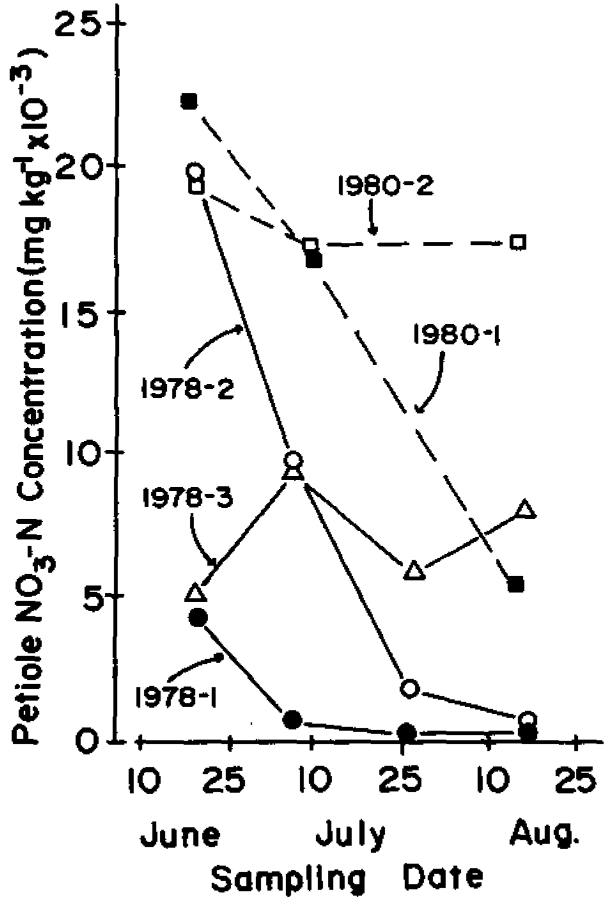

FIG. 3. The effect of N treatment and year on petiole NO_3-N concentrations at selected sampling dates.

A preliminary study showed that potato petiole NO_3-N concentrations increased from 3,000 to 20,200 mg kg^{-1} six days after a 45 kg N ha^{-1} application as urea on 20 June. A change of 10,000 mg kg^{-1} NO_3-N in the potato petioles and stems would be equivalent to a total N content change of about 22 kg ha^{-1} in the plant. Rapid plant NO_3-N uptake and temporary storage in the petioles and stems may account for part of the high seasonal N recoveries. Similar recoveries might also be expected for urea-ammonium nitrate solutions applied during active tuber growth.

The petiole NO_3-N concentrations were lower than 10,000 mg kg^{-1} in all 1978 treatments by 1 July (Figure 3). The soil NO_3-N concentrations were also less than 5 mg kg^{-1} after 1 August. These concentrations indicate that the plant's N uptake rate would not be sufficient to prevent a net loss of N and dry matter from the tops and roots to the tubers (16). Nitrogen applied under these conditions would probably be rapidly taken up and utilized by the plant (Figure 2B and 2C). This situation may enhance N recoveries, since the applied N would not be available for loss by other mechanisms, *e.g.*, leaching, denitrification.

The soil NO_3-N concentration in the 1980-2 treatment was above 10 and 6 mg kg^{-1} on 1 August and 19 September, respectively (data not shown). This, combined with greater than 17,000 mg kg^{-1} petiole NO_3-N concentrations (Figure 3), indicates that N was probably not limiting growth in this treatment. Soluble P concentrations in this treatment's petioles were less than 1,000 mg kg^{-1} by 23 July (data not shown). Below this concentration, the P uptake rate is not sufficient for tuber growth and P is lost from the tops and roots by translocation to the tubers (15). An active top, *i.e.*, leaves, is necessary for nitrate assimilation since most of the nitrate reductase is in the leaves (13). This apparent P deficiency would cause a premature plant senescence and thereby reduced the ^{15}N recovered from the 11 August 1980 N application. This is supported by the leveling off of total N uptake after 15 August 1980 (Figure 1).

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