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Dry Matter Production and Nitrogen Utilization by Six Potato Cultivars[1]

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ABSTRACT

The rate and duration of tuber growth largely determines the final potato (*Solanum tuberosum* L.) tuber yields. Cultivars that continue leaf development and nutrient uptake while maintaining maximum tuber growth rates may have higher final tuber yields, yet different N requirements. The objective of this study was to obtain information relating plant growth rates to N availability for selected potato cultivars. Total dry matter accumulation and N assimilation patterns of indeterminant cultivars, 'Russet Burbank', 'Lemhi Russet', 'Centennial Russet', and one advanced selection A66107-51, were compared with that of two determinant cultivars, 'Pioneer' and 'Norgold Russet', at three N levels. Cultivars were grown in a field experiment on a Portneuf silt-loam soil (Xerollic Calciorthids).

High available soil N levels at planting delayed the linear potato tuber growth period 7 to 10 days but had minor effects on the time of tuber initiation for the indeterminant varieties. Maximum tuber growth rates (tuber bulking) were 900 to 1,300 kg/ha/day. A66107-51 was superior in N-use efficiency to the other cultivars. Between 70 and 100% of the total available N was utilized by this cultivar in producing high yields. This information may be used to select lines and cultvars that will optimize production. A knowledge of plant growth and N uptake rates can improve the fertilizer recommendations for each cultivar.

Additional index words: *Solanum tuberosum* L., N-use efficiency, Tuber growth.

THE yield and quality of potatoes (*Solanum tuberosum* L.) is strongly affected by fertility levels. High N applications can delay tuber bulking (Ivins and Bremner, 1965; Moorby and Milthorpe, 1975) and increase the shoot-to-root ratio (Sommerfeldt and Knutson, 1968). Some evidence suggests that N may function in a regulatory role promoting or delaying tuberization or tuber number (Wilcox and Hoff, 1970; Dubetz and Bole, 1975; Moorby and Milthorpe, 1975). Krauss (1978a, 1978b) showed that N fertility could change the GA/ABA ratio influencing tuber growth. Nitrogen also has been reported to play a major role in the production and maintenance of optimum plant canopy for continued tuber bulking through long growing seasons (Bremner and Taha, 1966; Bremner and Radley, 1966; Moorby, 1978).

The nutrient content and assimilation by the plant are the results of total plant growth rates and nutrient availabilities (Augustin et al., 1977; Carter and Bosma, 1974; White et al., 1974; Soltanpour and Cole, 1978; Lorenz et al., 1974). Dry matter production rates of tubers also vary with variety and season (Kunkel, 1968; Soltanpour, 1969; Smith, 1977; Sale, 1973). During periods of high tuber growth rates, the demand for nutrients by the developing tubers may cause translocation of nutrients out of the tops into the tubers, resulting in early senescence of the tops (Dyson, 1965; Harris, 1978). Cultivars that are capable of continued leaf development and nutrient uptake during periods of high tuber growth may have higher tuber yields, if other environmental conditions are not limiting.

The objective of this work was to obtain definitive plant growth responses to N uptake, assimilation, and redistribution for selected potato cultivars. This information would be useful in plant breeding programs for improving N-use efficiency and in developing fertilization practices for specific potato cultivars.

MATERIALS AND METHODS

The potato varieties used in this study were all commercially available, except one advanced selection from the USDA potato breeding program at the University of Idaho Research and Extension Center, Aberdeen, Idaho. Two potato plant growth types were compared. Indeterminant cultivars are semivining, mid to late-season maturing, and included 'Lemhi Russet', 'Russet Burbank', and 'Centennial Russet', and one advanced selection A66107-51. Determinant cultivars are non-vining, early to mid-season maturing, and included 'Norgold Russet' and 'Pioneer'. Late-season cultivars are used mainly for processing, whereas early-season cultivars are used primarily for fresh market stock. A more complete description of these potato cultivars is available (Garner et al., 1978).

The potato cultivars were planted on a Portneuf silt-loam soil (Xerollic Calciorthids) between 19 and 25 April in 1977, 1978, and 1979 after cereal grains to ensure a relatively low residual soil-N level. Seed piece spacing was 23 cm for all cultivars (Ohms, 1962), except A66107-51 which was 15 cm in 1978 and 1979. Individual plots were 6 m × 30 m with 91-cm row spacing. A completely randomized design was used with six variables, three treatments, and three replications.

All fertilizer materials were applied preplant and incorporated into the top 15 cm of soil. Phosphorus, K, and micronutrient applications were based on University of Idaho soil test recommendations (Painter et al., 1977). Preplant soil NO_3-N ranged between 30 and 60 kg/ha N in the top 45 cm of soil. Nitrogen was applied to the field plots as NH_4NO_3 to provide three treatments: N1, no fertilizer N applied; N2, 270 kg/ha (recommended rate which usually provides adequate N for a yield of 56 metric tons/ha for Russet Burbank cultivar); and N3, 1.5 times the recommended rate. All potato cultivars were grown under similar field conditions at each of the three N levels.

All plots were irrigated by solid set sprinklers with 12-m spacing between sprinkler heads and lines, when the available soil moisture dropped to 50%. The soil moisture level was

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monitored with tensiometers placed in the row at the seed piece depth. Metribuzin (4-amino-6-(1, 1-dimethylethyl)-(methylthio)-1,2,4-trizain-5(4H)-one) herbicide and Aldicarb (2 methyl 2-3 (methylthio) propionaldehyde 0 - (methylcarbamoyl) oxime) insecticide were used routinely in all field studies at 0.8 kg/ha (ai) and 3.3 kg/ha (ai), respectively.

Whole plant samples (1.5-m row) from each replication were taken at 2 week intervals from emergence to final harvest. Plants were separated into leaves, stems, roots, and tubers. Tuber number and their combined fresh weight was recorded at each sampling peroid. Leaf area was measured on the separated leaves with a Li-Cor Leaf Area Meter, Model 3100. Plant tissue was dried at 60 C and ground to pass through a 40-mesh screen. Nitrogen content of the plant tissue was measured by semi-mirco-Kjeldahl analysis modified to include nitrate (Bremner, 1965).

Soil samples (0 to 45 cm) for nitrate (NO_3-N) analysis (Milham et al.,1970) were taken from the treatment N1 at each plant sampling period. Soil-N mineralization was measured by a buried polyethylene bag technique (Westermann and Crothers, 1980). Changes in N contents of the plant and soil were used to calculate plant uptake rates, soil mineralization rates, and N balance information for each potato cultivar. Total available N included the preplant soil NO_3-N content, that mineralized during plant growth, and fertilizer N. Data were analyzed by analyses of variance and Duncan's Multiple Range Test. The N-use efficiency (NUE) is defined as the ratio of total N uptake at the preharvest sampling to the total available N for that treatment.

RESULTS AND DISCUSSION

Dry matter distribution curves for both the determinant and indeterminant cultivars were similar. Data presented in Fig. 1 for the two cultivars are representative of the two plant growth types. Determinant cultivars, under optimum conditions, completed their growth cycle within 60 to 80 days after emergence, whereas indeterminant cultivars needed 100 or more days (Fig. 1).

The dry matter accumulation and distribution in the plant can be described by dividing growth stages into four periods, based on top and tuber growth and N uptake. During Growth Stage I, "vegetative", plants develop from planting until the start of tuber initiation. This period ranges from 30 to 70 days, depending upon planting date, soil temperatures, seed age, variety differences, and other environmental factors affecting growth. Growth Sage II, "tuberization", lasts 10 to 14 days, with tubers being formed at the tips of the stolons but not appreciably enlarging. The primary inflorescence may have a few open flowers at the end of this stage. Growth Stage III, "tuber growth", is the phase where tuber growth is linear if all growing conditions are adequate. During Growth Stage IV, "maturation", vines start to yellow, leaf loss is evident, and the tuber growth slows. The increase in tuber dry weight during maturation results mainly from translocation of materials from the tops and roots.

Nitrogen uptake (Fig. 2) preceded dry matter accumulations (Fig. 1) and varied with growth stage. By the end of Growth Stage II, the plants had taken up 60% of the total seasonal N requirement but had produced only 20% of the total dry matter. At the end of Growth Stage III, the plants contained 98% of the final N uptake and 95% of the total dry matter production; however, only 80% of the tuber dry weight had been produced. Final maximum tuber yields required a movement of N and carbohydrates from the tops and roots into the tubers during Growth Stage IV.

Besides length of their growing period, determinant and indeterminant potato cultivars differ in their dry matter accumulation and N assimilation rates. The determinant Norgold Russet had a higher early growth rate of tops and tubers than did the indeterminant cultivars. The indeterminant Russet Burbank cultivar

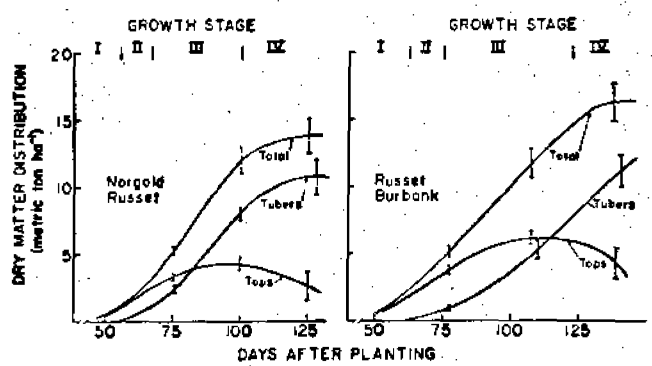

Fig. 1. Dry matter distribution in Norgold Russet (determinant) and Russet Burbank (indeterminant) cultivars for treatment N2 (fertilized at the recommended rate, based on the University of Idaho potato fertilizer guide). Data are 3-year averages. Vertical lines represent standard error.

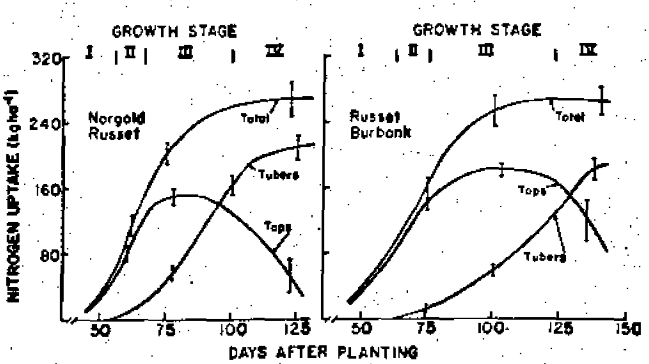

Fig. 2. Seasonal profile of N uptake in tubers, tops, and total plant by Norgold Russet and Russet Burbank cultivars for treatment N2 (fertilized at the recommended rate based on the University of Idaho potato fertilizer guide). Data are 3-year averages. Vertical lines represent standard error.

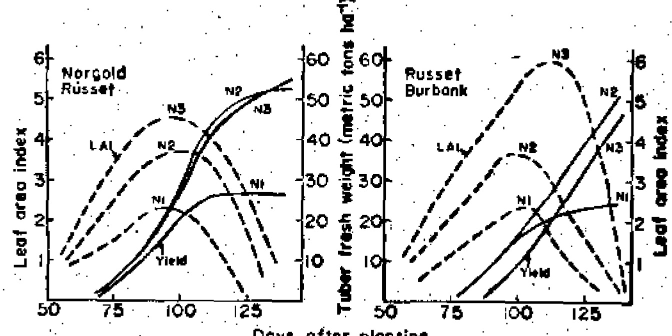

Fig. 3. Seasonal profile of leaf area index (LAI) (dashed lines) and tuber fresh weight (solid lines) of Norgold Russet and Russet Burbank cultivars. N1 = low, N3 = excess N application. LAI of both cultivars is significantly different (P >0.05) at all sampling intervals. N2 vs. N3 yield lines of Norgold Russet nonsignificant. N2 vs. N3 yield lines of Russet Burbank are significantly different (P>0.05) at all sampling intervals.

maintained an active leaf area longer, which may increase tuber yields if other factors are not limiting.

The leaf area index (LAI) and fresh tuber yields of the determinant Norgold Russet were compared with that of the indeterminant Russet Burbank (Fig. 3). With the exception of the very early sampling date, the LAI data are significantly different ($P \leq 0.05$) between all N treatments for a given cultivar. As available N increased, the LAI and tuber yields of both potato cultivars increased. In the Russet Burbank, an excessive application (N3) almost doubled the maximum LAI and delayed the onset of tuber enlargement 10 to 14 days, but did not increase the tuber growth rate as compared with the N2 treatment (fertilized at the recommended rate). The tuber yields of Russet Burbank from the N2 and N3 treatments are significantly different ($P \leq 0.05$) at all sampling dates. Final tuber yields for the N3 treatment might be greater than that for the N2 treatment with an extended growing season. However, in an area where frost may limit the growing period, excess N could decrease yields. Insufficient N (N1 treatment) reduced tuber growth rate, resulting in premature plant death, and lowered final tuber yield. A LAI between 3 and 4 seemed to be optimum for maximum tuber growth rates under these conditions (Fig. 3). Nitrogen rates considered to be excessive did not seem to delay tuber enlargement and rarely produced higher yield in determinant potato cultivars (Norgold Russet and Pioneer).

The total seasonal N requirement of the six potato cultivars depended upon growth rates (tops and tuber) and total time of plant growth. The average maximum tuber growth rates for the six cultivars are presented in Table 1. The whole plant N utilization rates necessary to support the tuber growth rates through Growth Stage III are also shown in Table 1. This amount of N must be available from inorganic soil N, soil-N mineralization, and fertilizer-N applications. The relationships of tuber-N uptake to soil-N mineralized and soil-NO_3-N concentrations are shown in Fig. 4 for the N1 treatment. Soil-NO_3-N concentrations increased initially and then decreased to less than 3 μg/g during maximum plant growth. The continued N uptake by the tubers was due to the translocation of N from tops and roots. This caused premature plant senescence and eventually reduced tuber growth rates. Additional N fertilizer applications may have prevented the reduced tuber yields; however, a knowledge of the plant's growth rates and the N available from all sources would be necessary for an optimum N fertilization rate.

Table 1. Maximum tuber growth rates and range of N utilization rates of six potato cultivars.

Variety	Plant growth type†	Growth rate‡	N utilization
		kg/ha-day	kg N/ha-day
Russet Burbank	I	950	2.8–4.0
A66107-51	I	1,220	2.8–4.0
Lemhi Russet	I	1,000	2.5–4.4
Centennial Russet	I	900	2.8–4.0
Norgold Russet	D	1,200	3.0–4.5
Pioneer	D	1,350	3.5–5.5
$L.S.D._{0.05}$		178	NS NS

† I is indeterminant; D is determinant.
‡ Fresh tuber weight.

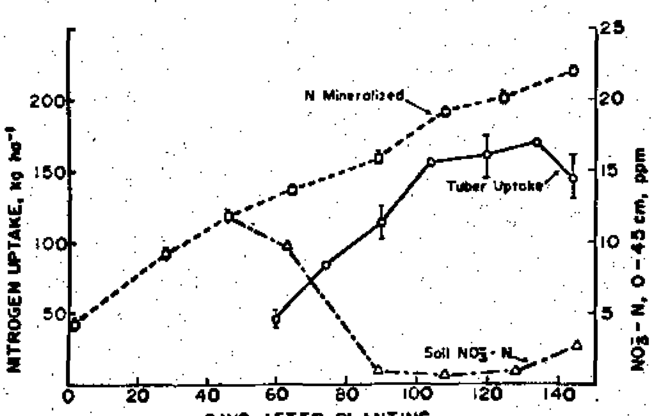

Fig. 4. Potato tuber N uptake, soil N mineralized, and soil NO_3-N concentrations during the growing season. Data are from an unfertilized (N1) treatment. Vertical lines represent standard error.

Tuber yields for all the cultivars except A66107-51 were generally increased by the N2 treatment compared to the N1 treatment (Table 2). Additional available N (N3 treatment) generally did not increase tuber yields and even reduced yields for three cultivars. The cultivars, A66107-51 and Pioneer, consistently had higher tuber yields than the other cultivars on the N1 and N2 treatments while only Pioneer was greater in the N3 treatment. A66107-51 had significantly greater tuber yields than the other cultivars on the N1 treatment when planted at the 23-cm seed spacing.

The NUE of all cultivars (23-cm spacing) decreased as the amount of available N increased. A66107-51 had a higher NUE than the other cultivars for all N treatments. Other NUE differences among cultivars only occurred on the N1 treatment. The NUE were not separated by plant growth types. The higher NUE for A66107-51 may be correlated to its resistance to *Rhizoctonia solani* Kuhn, a soil-borne fungus affecting root and stolon growth.

The tubers for A66107-51 were oversized, irregularly shaped, and had specific gravities of 1.068 and 1.066 when grown on the N2 and N3 treatments, respective-

Table 2. Average high tuber yield and N-use efficiency (NUE) of potato cultivars.†

	Total available N, kg ha⁻¹					
Cultivar‡	(N1) 170		(N2) 440		(N3) 570	
	NUE	Tuber yield	NUE	Tuber yield	NUE	Tuber yield
	%	metric ton/ha	%	metric ton/ha	%	metric ton/ha
Russet Burbank	68 a	25.8 a	64 ab	42.0 a	51 ab	43.1 a
A66107-51	97 c	60.6 d	87 c	51.0 b	68 c	39.1 a
Lemhi Russet	75 b	34.8 b	55 a	48.8 a	40 a	43.0 a
Centennial Russet	63 a	34.0 b	54 a	45.8 a	43 a	37.5 a
Norgold Russet	79 b	31.9 b	55 a	40.1 a	46 a	43.7 a
Pioneer	71 ab	40.8 c	57 c	59.4 bc	52 ab	57.1 b
A66107-51 (15 cm)	99 c	43.3 c	89 c	60.5 c	71 c	62.5 b

† NUE is the percentage of total N uptake at the preharvest sampling vs. total available N. Means within a column followed by a common letter do not differ significantly at the 0.05 probability level according to Duncan's Multiple Range Test.
‡ All cultivars were grown at a 23 cm seed piece spacing except as indicated for A66107-51.

ly, at the 23-cm seed piece spacing. These tubers would be rejected for processing, while the tubers grown under the 15-cm spacing were all acceptable. A vigorous evaluation of seed piece spacing is not possible, although both seed piece spacings had similar NUE's and total dry matter productions (data not shown) for a given N treatment. Total dry matter production in potatoes was shown to be a linear function of intercepted radiation (Allen and Scott, 1980). Total dry matter production and total N uptake were also independent of plant densities above on optimum density for a given N treatment (Bodlaender and Reestman, 1968). These data indicate that there is probably a significant interaction between available N and seed piece spacings on shoot: tuber ratios and tuber quality for at least this cultivar.

Determinant cultivars may require a different N fertility program than indeterminant since tuberization and N uptake occur earlier in the season when planted at the same time. The amount of soil N mineralized would also be lower when tuberization occurred for the determinant type. Early N fertilizer applications would then be more important for the determinant than for the indeterminant cultivar. A high available N level at planting should be avoided for indeterminant cultivars since it can delay the tuber growth period 7 to 10 days. This would be particularly important in areas with a limited growing season. Additional research is needed to determine the optimum amount of N that can be applied preplant for this plant growth type. Continued seasonal N uptake is necessary for maximum yields of both plant growth types. The total N uptake by either type would be dependent upon its total dry matter production.

Nutrient recommendations for potato production are available from research and extension personnel in nearly all potato growing areas (Kunkel and Thornton, 1980; Tyler et al., 1964; Terman et al., 1951; Painter et al., 1977). Data presented here shows that the response of the potato plant to the available nutrient supply is an important determinant for accurate fertilizer recommendations. It also suggests that N fertility recommendations should be developed for each cultivar and be based on its dry matter production rate and corresponding N uptake during each growth stage. This type of information may also be used by the plant breeder to develop cultivars with improved production and fertilizer-use efficiencies.

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