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Dry Matter and Nitrogen Accumulation and Root Morphological Characteristics of Two Clonal Selections of 'Russet Norkotah' Potato as Affected by Nitrogen Fertilization

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ABSTRACT

New clonal selections with increased vine vigor and stress resistance have been identified for the potato cultivar 'Russet Norkotah'. However, the importance of clonal variation in nitrogen (N) uptake and root morphological properties is not well known. The objective of this study was to determine the effect of N fertilization on dry matter and N accumulation and root morphological parameters of two clonal selections of 'Russet Norkotah'. A field experiment was conducted in 2002 using the standard 'Russet Norkotah' clone (SRC) and Texas selection 112 (TX112) of 'Russet Norkotah', grown at 0 and 150 kg N ha^{-1}. Whole plants were excavated at 54, 76, and 96 days after planting; partitioned into tubers, vines, roots, stolons, and fruits; and their dry matter and N accumulation were determined. Soil cores were obtained from 10 spatial locations relative to the plant, and used for determination of root length (RL), root length density (RLD), root average diameter (RAD), and root dry weight (RDW). Soil inorganic N content was also measured. Nitrogen fertilization increased tuber yield and dry matter and N accumulation. Fertilizer N application did not affect RL, RLD, or RDW, but resulted in a larger proportion of roots close to the top of the potato hill. Tuber yield and dry matter and N accumulation were similar for the two clonal selections. The TX112 clone, however, partitioned more dry matter and N to vines and less dry matter and N to tubers compared with the SRC clone. Soil nitrate concentration was significantly higher for SCR than for the TX112 clone in the fertilized treatment at 54 DAP, and was low and similar between

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clones thereafter. Root length and RLD were significantly higher for the TX112 clone compared with SRC, and both clones had a similar spatial distribution of roots. Under the conditions of this study where moisture and disease stress were limited and under a short growing season, the larger root system and increased vine vigor of the TX112 clone did not provide any advantage in terms of plant production as either dry-matter accumulation or tuber yield.

Keywords: root density, root diameter, root dry weight, root length, *Solanum tuberosum* L., tuber yield

INTRODUCTION

Potato production commonly occurs on sandy soils, with high fertilizer nitrogen (N) inputs and irrigation. The limited root system of the potato crop, in combination with these factors, frequently results in a high risk of nitrate leaching. While numerous studies have explored improved N-management practices as a strategy for minimizing N loss, there is potential for exploiting the genetic variability among cultivars and mutant strains of asexually propagated crop species such as potato for improved N uptake. Significant variations in N-use efficiency characteristics have been identified among potato cultivars, clonal selections, and ascensions of wild potato species (Errebhi et al., 1999; Zebarth et al., 2004; Zvomuya et al., 2002). This variation suggests that the potential may exist to reduce the risk of nitrate leaching through selection of more efficient potato cultivars or clonal selections of cultivars. Although plant breeders seldom select for nutrient-use efficiency, breeding programs that develop lines, which produce high yields may result in unconscious selection of genotypes that use nutrients more efficiently (Zvomuya et al., 2002).

The physiological basis of genotypic variation in N-use efficiency of potato is poorly understood. Sattelmacher et al. (1989) attributed differing N-uptake efficiency of two commercial potato cultivars to differences in root morphology. Modern potato clones generally had greater tuber yield per unit of root dry weight (RDW) compared with native clones cultivated in the Andes (Sattelmacher et al., 1990). This result suggests that root systems may be important in controlling potato N utilization.

'Russet Norkotah' was released as an early fresh market russet in 1987 (Johansen et al. 1988). This cultivar is popular because of its relatively high yield and excellent tuber type, and provides a high percentage of U.S. No. 1 tubers. However, this cultivar also has low vine vigor, is susceptible to early die-down, and requires higher fertilizer N inputs than many other cultivars (Zvomuya et al., 2002). Residual soil nitrate measured in commercial potato fields was almost twice as high for 'Russet Norkotah' as for 'Russet Burbank' and 'Shepody', suggesting an increased risk of nitrate leaching with 'Russet Norkotah' production (Zebarth et al., 2003). This effect was attributed to higher N-fertilization rates (Zebarth et al., 2003) and lower N-uptake efficiency

(Zebarth et al., 2004) for ‘Russet Norkotah’ compared with ‘Russet Burbank’ and ‘Shepody’.

Recent clonal selections of ‘Russet Norkotah’ have identified strains with higher yield potential and larger and stronger vines that may require lower fertilizer N inputs (Miller et al., 1995). Miller et al. (1995) demonstrated that clonal selection could result in the improvement of existing cultivars with modification of traits such as stronger vines, which can improve productivity under stressful conditions. New clonal selections of ‘Russet Norkotah’ from Texas produced greater biomass than the standard clone of ‘Russet Norkotah’ per kilogram of N applied when N rates were low and per kg of fertilizer N absorbed by the plant (Zvomuya et al., 2002). Their superior yield has been attributed to increased vine vigor and resistance to verticillium wilt (Miller et al., 1999). There is no information on differences in N uptake and root morphological characteristics of ‘Russet Norkotah’ clonal selections in Atlantic Canada.

The objective of this study was to determine the effect of N fertilization on dry matter and N accumulation and root morphological parameters of two clonal selections of Russet Norkotah.

MATERIALS AND METHODS

The study site was at Potato Research Centre, Agriculture and Agri-Food Canada, Fredericton, New Brunswick, Canada (at 45° 55′ N, long 66° 37′ W). Soils at the site were developed on medium-textured till deposits, and are classified as Haplorthods. The preceding crop was unfertilized spring wheat (*Triticum aestivum* L.). Soil (0–15 cm) had 505 g kg^{-1} sand, 346 g kg^{-1} silt, and 149 g kg^{-1} clay (hydrometer method); pH of 6.2 (1:1 water), and organic carbon content (Ca) of 20.7 g kg^{-1} (combustion method). Soil samples (0–30 cm) for determination of inorganic N content were collected at planting, at 54 and 76 days after planting (DAP), and after tuber harvest as a possible indicator of N uptake efficiency. Samples were frozen until analyzed. Soils were passed through a 4.75 mm sieve to remove coarse mineral fragments, extracted with 1.7 *M* KCl, and the extract was analyzed colorimetrically for NO_3^- and NH_4^+ concentrations using a Technicon TRAACS 800 auto-analyzer (Zebarth and Milburn, 2003).

A factorial arrangement of treatments in a randomized complete block design with four replications was used with two fertilizer N rates (0 and 150 kg N ha^{-1}) and two clonal selections of potato cultivar ‘Russet Norkotah’. The two clonal selections were the standard ‘Russet Norkotah’ (Johansen et al., 1988) and Texas 112 (Miller et al., 1999). Each plot contained six rows 10 m in length, with two outer rows acting as guards. Hand-cut 57 g (±4 g) seed was hand-planted on May 24 (2002) at 0.30 m within-row spacing in rows 0.91 m apart. Nitrogen fertilizer was applied as ammonium nitrate (NH_4NO_3), banded at planting approximately 7.5 cm to each side, and 5 cm below the seed pieces.

All plots received 150 kg P_2O_5 and K_2O ha^{-1}, also banded at planting. Standard commercial practices were used for tillage and weed, insect and disease control.

Root samples were taken on July 15 (vegetative growth stage, 54 DAP), August 6 (flowering stage, 76 DAP), and August 26 (tuber maturation stage, 96 DAP). One representative plant was taken from each plot at each sampling date. Roots were sampled using aluminum cores 15 cm long by 7 cm in diameter. Soil cores were taken from 0–15 and 15–30 cm depths, where zero elevation was taken as the soil surface at the top of the potato hill, and at six spatial locations relative to the plant, similar to Vos and Groenwold (1986). There is limited potato root growth below 30 cm depth in this region (Opena and Porter, 1999). Root samples were washed using a hydropneumatic elutriation root washer (sieve size = 0.47 mm) (Smucker et al., 1982). Roots were separated in a thin layer of water on a transparent tray with dark background and photos were taken using an Epson PhotoPC 750z digital camera (Resolution = 1280*960 pixels). Root photos were analysis by WinRHIZO Version 2002C PRO software (Arsenault et al., 1995). Root length (RL), root length density (RLD), and root average diameter (RAD) were calculated. Roots were dried at 55°C, weighed, and the N concentration was measured by combustion method using a Leco CNS-1000.

After core sampling, whole plants were excavated and partitioned into vine, stolen, tuber and fruit. Tuber fresh weight yield was determined. Each plant component was dried at 55°C and dry matter and N accumulation were determined as described by Zebarth and Milburn (2003). Amounts of maximum dry matter and N accumulations in fruits and stolons were small, and many fruits were on the soil surface at the time of sampling; consequently, fruits and stolons were excluded in the calculation of dry matter and N accumulation (Zebarth et al., 2004).

Data were subjected to analysis of variance (ANOVA) using the General Linear Model of SAS (SAS Institute Inc., Cary, NC, Version 8). The ANOVA for root parameters was performed using a statistical model that treated root-sampling location as a sub-plot, and sampling date as a sub-sub-plot, in a factorial design to assess the spatial distribution of root parameters. The ANOVA for plant parameters and for soil inorganic N contents treated sampling date as a sub-plot in a factorial design. Treatment means were compared using Fisher's protected least significant difference (LSD) test at 5% probability level. A logarithmic transformation of RDW and soil nitrate concentration was performed prior to statistical analyses.

RESULTS AND DISCUSSION

Tuber yield was increased by N fertilization for the SRC compared with the TX112 clone at 76 and 96 DAP (Figure 1). Unlike this study, previous studies have reported higher yield for Texas strains of 'Russet Norkotah' compared with

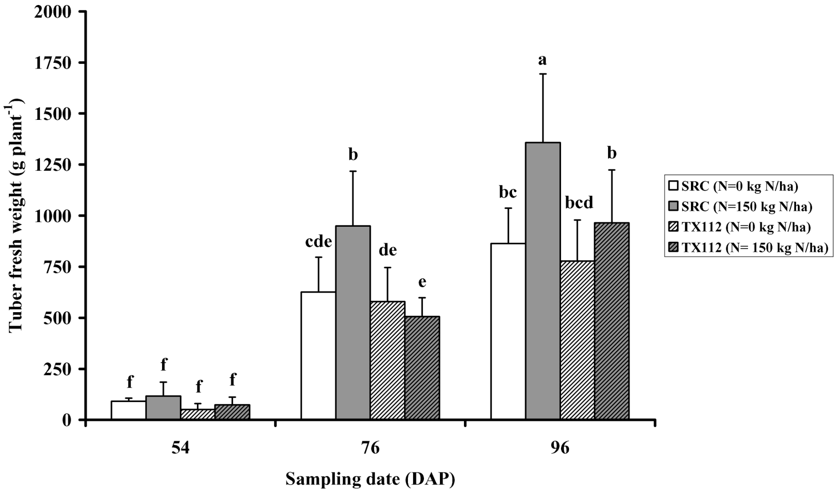

Figure 1. The effect of N fertilization on tuber fresh weight yield for standard (SRC) and Texas 112 (TX112) clones of potato cultivar 'Russet Norkotah' on three different sampling dates. Values with the same letter are not significantly different ($P > 0.05$). Bars represent 1 SD.

the standard strain (Miller et al., 1999). Improved performance of new 'Russet Norkotah' strains has been attributed to increased vine vigor and increased resistance to moisture and disease stress. The limited moisture and disease stress present in this study may have minimized the benefit of using a new clonal selection. In addition, the new clonal selections, which have a later tuber initiation and maturity compared with SRC, may be of more limited benefit under the short growing season conditions present in this study.

Nitrogen fertilization increased plant and vine dry-matter accumulation, but had no significant effect on tuber dry-matter accumulation (Figure 2). The two clones had similar plant dry-matter accumulation; however, the partitioning of dry matter among plant components differed among clones. At 96 DAP, 81.4%, 16.4%, and 2.2% of plant dry matter was present in tubers, vines, and roots for SRC compared with 69.0%, 27.2%, and 3.8% of plant dry matter present in tubers, vines, and roots for TX112. Zvomuya et al. (2002) also found that the standard 'Russet Norkotah' clone partitioned more dry-matter to tubers compared to three Texas strains of Russet Norkotah. The lack of increase in tuber dry-matter accumulation may reflect an abundant soil N supply. Alternatively, the growing season at the experimental site may not have been long enough for the increased canopy of the TX112 clone to translate into an increase in tuber yield.

Nitrogen fertilization increased plant N accumulation (Figure 3). Like plant dry-matter accumulation, the two clones had similar plant N accumulation, but differed in the partitioning of N among plant components. At 96 DAP, 66%,

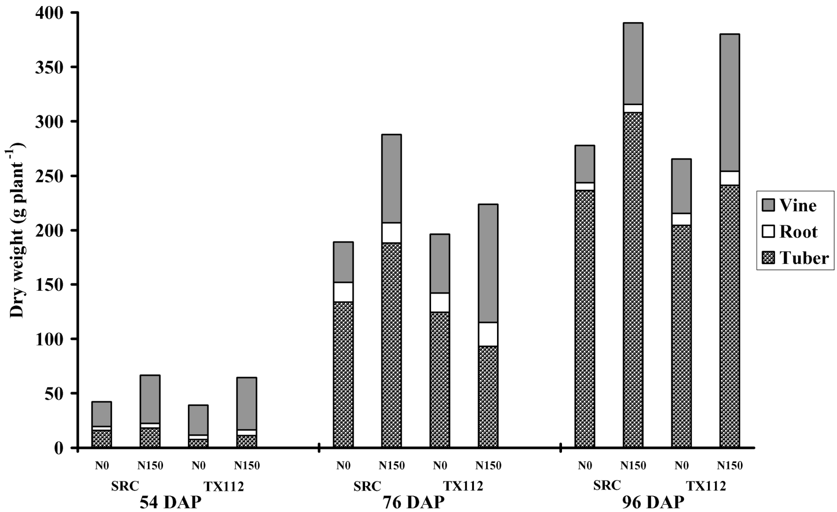

Figure 2. Dry-matter partitioning among plant components for standard (SRC) and Texas 112 (TX112) clones of potato cultivar 'Russet Norkotah' at three sampling dates (54, 76, and 96 DAP) as affected by two rates of N fertilization, 0 and 150 kg N ha^{-1} (N0 and N150, respectively).

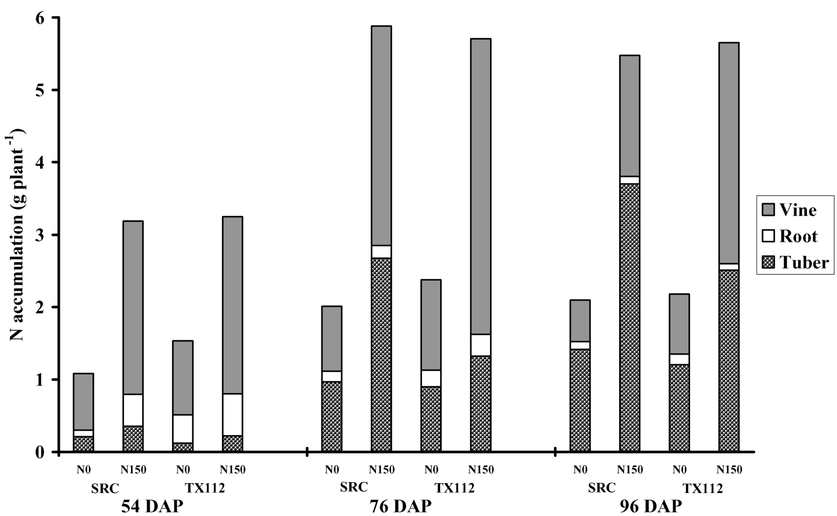

Figure 3. Nitrogen partitioning among plant components for standard (SRC) and Texas 112 (TX112) clones of potato cultivar 'Russet Norkotah' at three sampling dates (54, 76, and 96 DAP) as affected by two rates of N fertilization, 0 and 150 kg N ha^{-1} (N0 and N150, respectively).

Table 1
Root length (RL), root length density (RLD), root average diameter (RAD), and root/shoot ratio (R/S ratio) for standard (SRC) and Texas 112 (TX112) clones of potato cultivar Russet Norkotah

Clone	N-rate (kg N ha^{-1})	Sampling date (DAP)	RL (kg plant^{-1})	RLD (cm cm^{-3})	RAD (mm)	R/S ratio (m g^{-1})
SRC	0	54	0.22	0.25	0.41	10.0
		76	0.70	0.70	0.36	18.9
		96	0.67	0.66	0.35	19.9
	150	54	0.24	0.27	0.45	5.5
		76	0.67	0.69	0.36	8.5
		96	0.54	0.54	0.34	7.4
TX112	0	54	0.23	0.25	0.43	8.5
		76	0.75	0.73	0.36	14.4
		96	0.69	0.67	0.35	14.2
	150	54	0.28	0.33	0.41	5.8
		76	0.81	0.81	0.36	8.0
		96	0.62	0.64	0.35	4.9

Values are the weighted mean of all sampling locations.

28%, and 6% of plant N accumulation was present in tubers, vines, and roots for SRC compared with 47%, 44%, and 9% of plant N accumulation present in tubers, vines, and roots for TX112. Consequently, there was a large amount of N in the intact vines and dropped leaves of TX112 at the end of the season, and the fate of this N in the crop residue is uncertain. Zvomuya et al. (2002) reported that SRC partitioned 10% more N to tubers than did Texas selections.

In this study, most N uptake by the plant occurred by the second sampling date (76 DAP). Thereafter, translocation of N from the canopy to tubers occurred in response to tuber growth and soil N supply. Similarly, Osaki et al. (1993) reported that there was a time lag between potato maximum N and dry-matter accumulation.

Soil inorganic N content (0–30 cm) was low at planting at 7 kg NH_4-N ha^{-1} and 14 kg NO_3-N ha^{-1}. At 54 DAP, soil nitrate and ammonium concentrations were higher where fertilizer N was applied, and higher for SRC than for TX112 (37 compared to 28 μg g^{-1} NO_3^- and 12 compared to 6 μg g^{-1} NH_4^+, respectively). After 54 DAP, soil nitrate and ammonium concentrations were low and did not differ between clones or between fertilizer N rates. The highest risk of nitrate leaching, therefore, is early in the growing season prior to rapid N uptake by crop, especially in coarse-textured soils.

Nitrogen fertilization did not have any significant effect on root morphological characteristics (Table 1). However, significant interactions of N fertilization by sampling location and sampling date were detected. Fertilizer N application resulted in an increase of RL and RLD at 0–15 cm depth in the hill position at plants and of RDW at locations in the center of the hill both at and between plants. Nitrogen fertilization also decreased the R/S ratio of both clones.

Root length, RLD, and RDW were significantly higher for the TX112 clone than for SRC, whereas RAD was similar for both clones (Table 1). The R/S ratio was higher for SRC than for the TX112 clone in non-fertilized treatments.

Root length, RLD, RDW, and RAD varied significantly among spatial locations. Root length, averaged across N fertilizer treatments and across clones, was 0.21 km plant^{-1} for 0–15 cm depth and 0.33 km plant^{-1} for 15–30 cm depth. Maximum values of RLD were measured for 0–15 cm depth at the hill and shoulder sampling positions, both at and between plants, whereas minimum values of RLD were measured in the furrow (Figure 4). Maximum values of RDW were measured at the hill sampling positions at plants, whereas minimum values of RDW were measured in the furrow. Root average diameter was higher for 0–15 cm depth at the hill at plant position (average 0.43 mm), than for other sampling locations (average 0.36 mm).

Root growth generally continued until 76 DAP, after which it decreased slightly due to fine root turnover (Vos and Groenwold, 1986; Lesczynski and Tanner, 1976). Maximum values of RL and RLD were measured at 76 DAP, with values of 0.81 km plant^{-1} and 0.81 cm cm^{-3}, respectively (Table 1). These values of RL and RLD are small in comparison with previously published values for potato: 3.4–7.0 km m^{-2} RL and 1.0–2.0 cm cm^{-3}RLD for cultivar 'Bintje' (Vos and Groenwold, 1986); 12–15 km m^{-2} RL and 1.3–6.0 cm cm^{-3}RLD for cultivar 'Russet Burbank' (Lesczynski and Tanner, 1976) and for some European cultivars (Stalham and Allen, 2001). Maximum values of RDW in this study ranged from 68 to 81 g m^{-2} (18.5–22.0 g plant^{-1}) for the SRC and TX112 clones, respectively. These values are comparable with previously reported RDW values: 38 and 77 g m^{-2} in two years for 'Bintje' (Vos and Groenwold, 1986) and 100–160 g m^{-2} for 'Russet Burbank' (Lesczynski and Tanner, 1976). Root average diameter in this study (0.34 mm), was greater than previously reported values. Lesczynski and Tanner (1976) stated that the major portion of 'Russet Burbank' potato roots had diameters of less than 0.2 mm, and Vos and Groenwold (1986) found that 91% of root diameters were smaller than 0.44 mm.

The two clonal selections compared in this study varied in term of root morphology. The standard 'Russet Norkotah' clone has higher RL, RLD, and RDW but similar RAD and spatial distribution of roots. By comparing root-parameter values obtained in this study with previously published results (Vos and Groenwold, 1986; Lesczynski and Tanner, 1976; Stalham and Allen, 2001), it may be concluded that cultivar 'Russet Norkotah' has a shorter length of larger-diameter roots, which may pose a higher risk of nitrate leaching, especially in coarse soil textures, than other potato cultivars. According to a root distribution study, 0–15 cm depth at the hill and shoulder positions are the

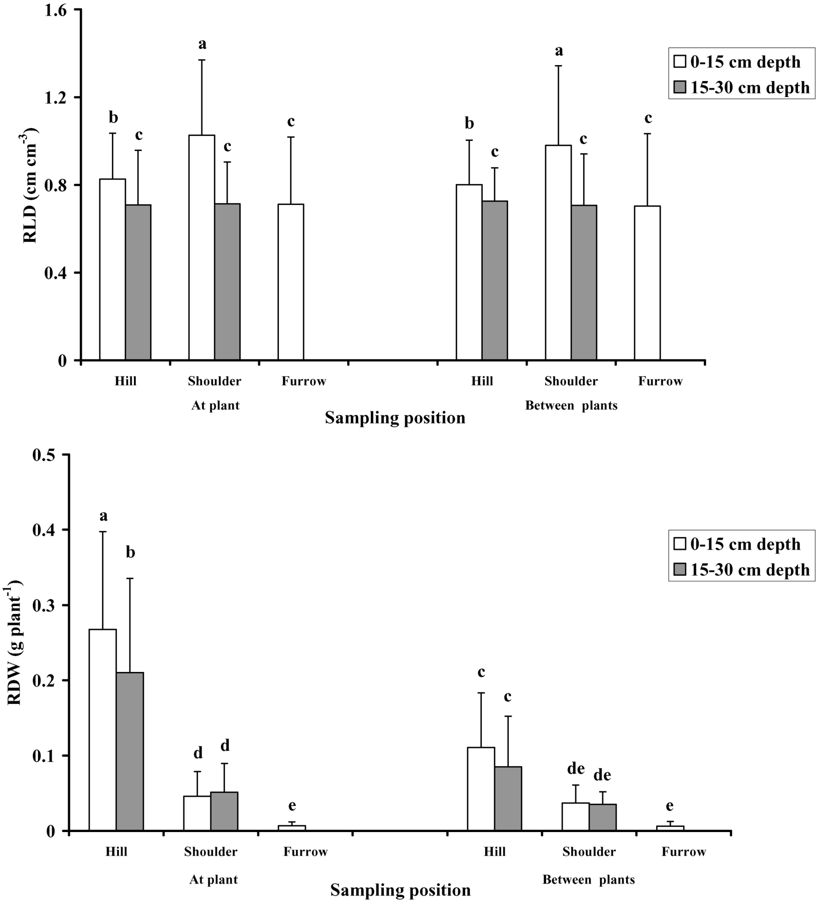

Figure 4. Root length density (RLD) and root dry weight (RDW) at 76 DAP, in three sampling positions and for two soil depths, measured either at or between plants, and averaged across clonal selections and N rates. Values with the same letter are not significantly different ($P > 0.05$). Bars represent 1 SD.

most important root locations, which should be considered in fertilization and cultivation management decisions.

Under the conditions of this experiment, where moisture and disease stress were limited and the growing season was short, differences in dry matter and N accumulation and root morphology among the two clonal selections of 'Russet Norkotah' did not translate into a significant effect on plant productivity as either dry-matter accumulation or tuber yield. However, the TX112 clone may have a reduced risk of nitrate leaching early in the growing season. Nitrogen fertilization increased mostly vegetative growth, N accumulation, and risk of nitrate leaching to groundwater, especially in the early season.

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