AN EVALUATION OF THE T-SUM METHOD FOR EFFICIENT TIMING OF SPRING NITROGEN APPLICATIONS ON FORAGE PRODUCTION IN SOUTH COASTAL BRITISH COLUMBIA

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Seven field trials were conducted over 3 years (1984–1986) at two locations (Agassiz and Oyster River) in south coastal British Columbia to determine forage response to 100 kg N ha^{-1} applied at various time intervals in the spring according to the accumulation of average air temperatures above 0°C from 1 Jan. (T-sum). A T-sum of 200 has been reported to be the optimum time for N application in western Europe and the United Kingdom. Both urea and ammonium nitrate were applied at the Oyster River location, while only ammonium nitrate was applied at Agassiz. First-cut forage dry matter production responded to the timing of N application in a variety of ways in the seven trials, with a decrease in growth as N was applied later in the season in most cases. In one trial, dry matter production was lowest at T-100 and T-150 compared to later times of application. Although there were variations among the trials, overall the highest yields occurred when N was applied at T-200 to T-300. Crop quality (%N or crude protein content), however, tended to increase as N was applied later in the season. Recovery of N in the plant and soil at harvest was relatively uniform for all times of N application and the distribution of extractable inorganic N in the soil profile suggested little N leaching. The dominant form of inorganic N found in the soil was ammonium. The cool soil temperatures and flush of plant and microbial activity probably contributed to the apparent lack of leaching and response of the grass to the N applied at various times early in the growing season. The timing of N application in the spring resulted in varying residual effects, whether N was applied or not after the first cut.

Key words: N fertilization, yield, quality, timing, N recovery

[Évaluation de la méthode de la somme des T pour déterminer l'opportunité d'applications printanières d'azote pour la production fourragère sur la côte sud de la Colombie-Britannique.]

Titre abrégé: Méthode de la Somme des T pour synchroniser les applications printanières d'azote sur des plantes fourragères.

Sept essais en plein champ ont été effectués pendant trois ans (1984–1986) à deux endroits (Agassiz et Oyster River) sur la côte sud de la Colombie-Britannique pour déterminer la réaction de cultures fourragères à l'application de 100 kg de N ha^{-1} à divers intervalles de temps avant l'arrivée du printemps selon l'accumulation des températures moyennes de l'air au-dessus de 0°C à partir du 1er janvier (Somme des T). Une

Somme des T de 200 semble être le moment le plus propice à l'application d'azote en Europe de l'Ouest et au Royaume-Uni. Au Canada, on a appliqué de l'urée et du nitrate d'ammonium à Oyster River, et seulement du nitrate d'ammonium à Agassiz. La production de matière sèche du fourrage de première coupe a réagi à l'opportunité de l'application d'azote de diverses façons au cours des sept essais, dans la plupart des cas par une baisse de la croissance suite à une application plus tardive d'azote. Dans un essai, la production de matière sèche est la plus faible à T-100 et T-150 comparativement à des temps d'application plus tardifs. Même si on constate des variations parmis les essais, l'application d'azote effecutée de T-200 à T-300 donne les rendements globaux les plus élevés. Mais la qualité de la récolte (% d'azote ou teneur en protéines totales) a tendance à augmenter lorsque l'azote est appliqué plus tard en saison. La récupération d'azote dans les plants et le sol à la récolte est relativement uniforme pour tous les temps d'application d'azote, et la distribution de l'azote inorganique extractible dans le profil du sol laisse croire à un lessivage restreint de l'azote. La forme dominante d'azote inorganique trouvé dans le sol est l'ammonium. Les températures fraîches du sol et la poussée d'activité végétale et microbienne ont probablement contribué à l'absence apparente de lessivage et à la réaction de la graminée à l'application d'azote à divers moments au début de la saison de croissance. L'opportunité de l'application d'azote au printemps entraîne divers effets résiduels, peu importe si l'azote a été appliqué après la première coupe ou non.

Mots clés: Fumure azotée, rendement, qualité, opportunité, récupération d'azote

Nitrogen is recognized as an important factor for intensive grass production (Corrall 1983; Prins and Arnold 1980). However, only a limited amount of field work has been reported on the response of forage grass to N fertilization in south coastal British Columbia (Kowalenko 1987a), an intensively farmed area. Bomke and Bertrand (1983) observed varying responses by a mixed-grass sward to the rate, form and splitting of N application in the Fraser Valley. In continental Europe, and subsequently in the United Kingdom, increased production has been observed by timing spring application of N according to an accumulation of average daily air temperatures above 0°C from 1 Jan. to a total of 200°C (UKF Fertilizers 1984).

The climate of south coastal British Columbia, although similar in some respects, has greater winter and early spring precipitation than in north-western Europe and the United Kingdom. Consequently, there is a risk of leaching of applied N early in the season and recommendations from Europe may not be applicable here. Furthermore, winter soil temperatures of south coastal British Columbia are frequently high enough for microbial activity (Kowalenko 1987b). Roots of apples (*Malus domestica* Bork.) and filberts (*Corylus avellana* L.) were observed to be active in the Vancouver area during the winter months (Harris 1926). It seems obvious that under these weather conditions, timing of spring N applications on perennial crops, according to plant activity rather than a set calendar date, would be prudent. To substantiate this theory, a series of field trials was initiated in 1984 and 1985 independently at two locations to determine the suitability of the T-sum method for timing spring N applications for south coastal British Columbia grass production. Soil analyses were included to examine the fate of the applied N, a measurement that has been neglected in previous field N trials in British Columbia (Kowalenko 1987a). The influence of the form of N and the time of application on forage quality and residual effects were also examined.

MATERIALS AND METHODS

The field trials were at two locations, one at Agassiz Research Station at the eastern end of the lower Fraser Valley and the other at the University of British Columbia Research Farm at Oyster River on Vancouver Island. Since the trials at the two locations were initiated independently, the treatments and some of the methodology differed. The general approaches were similar enough to examine and report on the two trials together. The primary objective was to examine the response of the first cut of the forage; however, some assessments of residual effects were made on subsequent cuts within the year of N treatment. At both locations, the trials were conducted on established mixed grass stands with orchardgrass (*Dactylis glomerata* L.) as the dominant grass species but with perennial ryegrass (*Lolium perenne* L.) and red and ladino clover (*Trifolium pratense* L. and *T. repens* L., respectively) also present. At Agassiz, the 1984 and 1985 trials were on a forage stand established in 1982 and the 1986 trial was on forage established in 1980. At Oyster River, Bill's field was established in 1978 and River field in 1984. The trials conducted at Agassiz in 3 consecutive years (1984–1986) included the application of 100 kg N ha^{-1} as ammonium nitrate on dates which approximated T-sums 100, 150, 200, 250, 300, 350, and 400. In 1985 and 1986, a treatment that received no N (control) was also included when it was realized that the net response of the crop and net fertilizer recovery in the soil to N treatment would be useful. The Oyster River trials, conducted in 1985 and 1986 on two fields (River and Bill's), included N applied at 100 kg ha^{-1} as ammonium nitrate or urea. The N was applied at T-sums approximating 100, 200, 300, 400, 500 and 600 in both years of the study. The trial on Bills' field did not include the T-600 treatment in 1985. Control plots receiving no N were included in each of these trials. The experimental units at both locations consisted of 1.8 × 6.1-m plots. The designs were randomized complete blocks with four replications. Phosphorus (50 kg P ha^{-1}) and potassium (50 kg K ha^{-1}) were broadcast over the entire trial area prior to the first N application to ensure that they were not limiting for the first cut.

The T-sum value was determined by accumulating the average daily air temperature (mean of minimum and maximum values) above 0°C from 1 Jan. in each year without subtracting mean values below freezing (UKF Fertilizers 1984).

The forage was harvested with a flail mower and a field fresh weight was taken. A subsample was oven-dried at 65-70°C for moisture correction and subsequent N determination. The first cut was taken in early to mid-May. Subsequent cuts were taken late June/early July, mid-August and mid- to late September. Only the first two cuts were weighed each year at Oyster River, while yields were determined for all four cuts taken each season at Agassiz. Fertilizer was applied at 75, 20 and 40 kg ha^{-1} of N, P and K, respectively, over the entire plot area after each cut at Agassiz to examine the residual effect as would occur under a simulated farm practice, whereas no fertilizer was applied after the first cut at Oyster River to examine the true residual effect of the spring applied N. The samples from Agassiz were analyzed for acid detergent fiber (Waldern 1971) and Ca, P, Mg, K, Cu, Zn, Mn, Fe and Na by inductively coupled plasma atomic emission spectrometry after nitric/perchloric acid digestion.

Soil samples were taken from each trial just prior to the N applications and then again after the grass was harvested. Soil samples at depths of 0–0.15, 0.15–0.30, and 0.30–0.60 m were taken from both locations for each trial except in 1985 at Oyster River when only a 0- to 0.30-m-depth sample was taken from both fields. Soil samples were refrigerated immediately after they were taken, then air-dried as soon as possible thereafter. Bulk densities representative of the sampling depths of the Agassiz and Oyster River locations were determined and were used to convert soil values from a weight to a volume basis. The soil at Agassiz is Monroe series which is an Eutric Eluviated Brunisol formed from medium-textured, stone-free Fraser River floodplain deposits overlying coarse-textured deposits (mainly sand), and is moderately well to well drained (Luttmerding 1981). The two trials at Oyster River were about 1 km apart, both on Qualicum series soil which is an Orthic Dystric Brunisol formed from coarse-textured, gravelly fluvial/glaciofluvial deposits that are rapidly drained (Jungen 1985). Total surface (to 0.15 m) soil N contents (Bremner and Mulvaney 1982) were 0.177 (SE=0.004), 0.142 (SE=0.003), 0.262 (SE=0.009) and 0.245 (SE=0.013)%, organic matter contents (by loss on ignition at 450°C) were 5.7 (SE=0.2), 5.1 (SE=0.2), 11.0 (SE=0.5) and 10.1 (SE=0.3)% and pHs (by electrode on 2:1 water:soil mixture) were 5.2 (SE=0.05), 5.6 (SE=0.1), 5.2 (SE=0.3) and 5.1 (SE=0.04), for 1984/1985 fields at Agassiz, 1986 field at Agassiz, Bill's field at Oyster River and River field at Oyster River, respectively.

The N content of the plant material was digested by a modified Kjeldahl procedure (Isaac and Johnson 1976) and the ammonium determined by hypochlorite-salicylate-nitroprusside colorimetric method on a Technicon autoanalyzer. Soil-extractable ammonium was determined by pH indicator colorimetry after an alkaline diffusion and

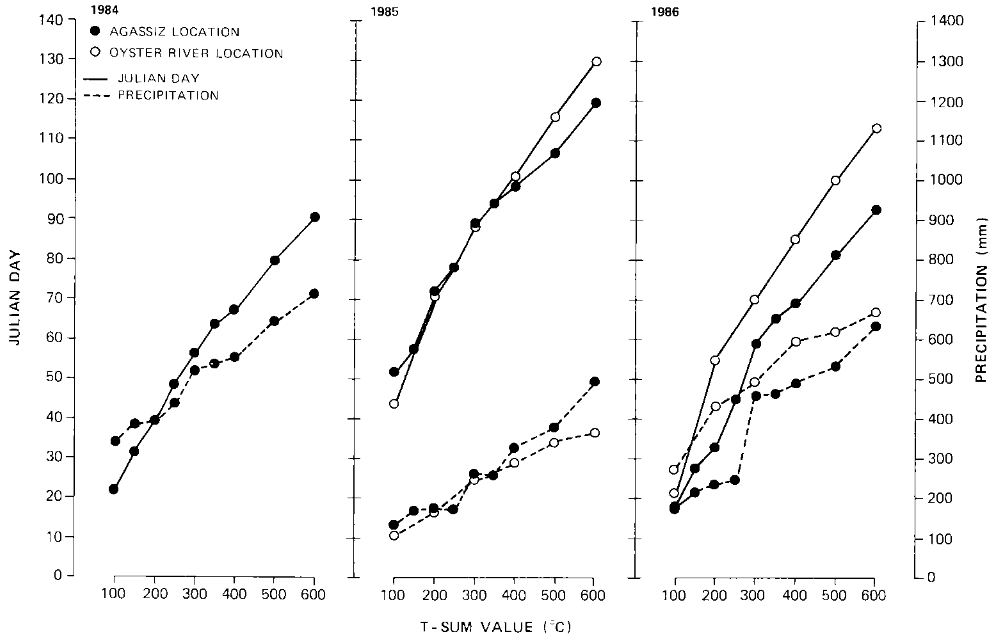


Fig. 1. Julian day occurrence and accumulation of precipitation at various T-sum values for two locations during which N application studies were conducted in south coastal British Columbia.

nitrate by sulfanilamide colorimetry after copper-cadmium reduction to nitrite using a Tecator flow injection analyzer on 1:10 2 M soil weight:KCl volume extractions. Urea was determined by diacetyl monoxime colorimetry on a 1:10 extraction with 2 M KCl containing phenylmercuric acetate as an enzyme inhibitor (Bremner 1982). Clay-fixed ammonium was determined by a KOBr-HF method (Keeney and Nelson 1982).

Treatment effects were examined by analysis of variance which included appropriate contrast analyses to determine whether N applications were different from the control (no N application) and orthogonal polynomials to determine the linearity of the response to N applied at various T-sums. A significance level of 5% was used.

RESULTS

The date at which T-sum 100 occurred differed more from year to year than between the two locations (Fig. 1). T-sum 100 was reached as early as 22 Jan. and as late as 22 Feb. in the 3 yr of the study. The accumulation of heat units was relatively steady, with slight differences in pattern from year to year and between the two locations. Precipitation tended to accumulate from T-100 to T-600 and ranged from 257 to 514 mm over that temperature accumulation interval. There was particularly heavy precipitation at Agassiz on 23-24 Feb. 1986 (151 mm), which occurred between T-200 and T-250. This did not occur at Oyster River.

There was an effect of time of N application on first cut-dry matter yield of forage in six of the seven trials conducted (Fig. 2). In three of the six trials, there was a linear decrease in dry matter production as N was applied at a later date. In the other three trials, the response was curvilinear with a maximum response tending to occur around T-sum 100-300, with Oyster River fields showing lowest yield response at T-sums greater than 200 and the Agassiz site showing lowest yield response at T-sum below 200. The response was consistently curvilinear at the River field and linear at Bill's field over the 2 yr the trial was conducted at Oyster River. In all six

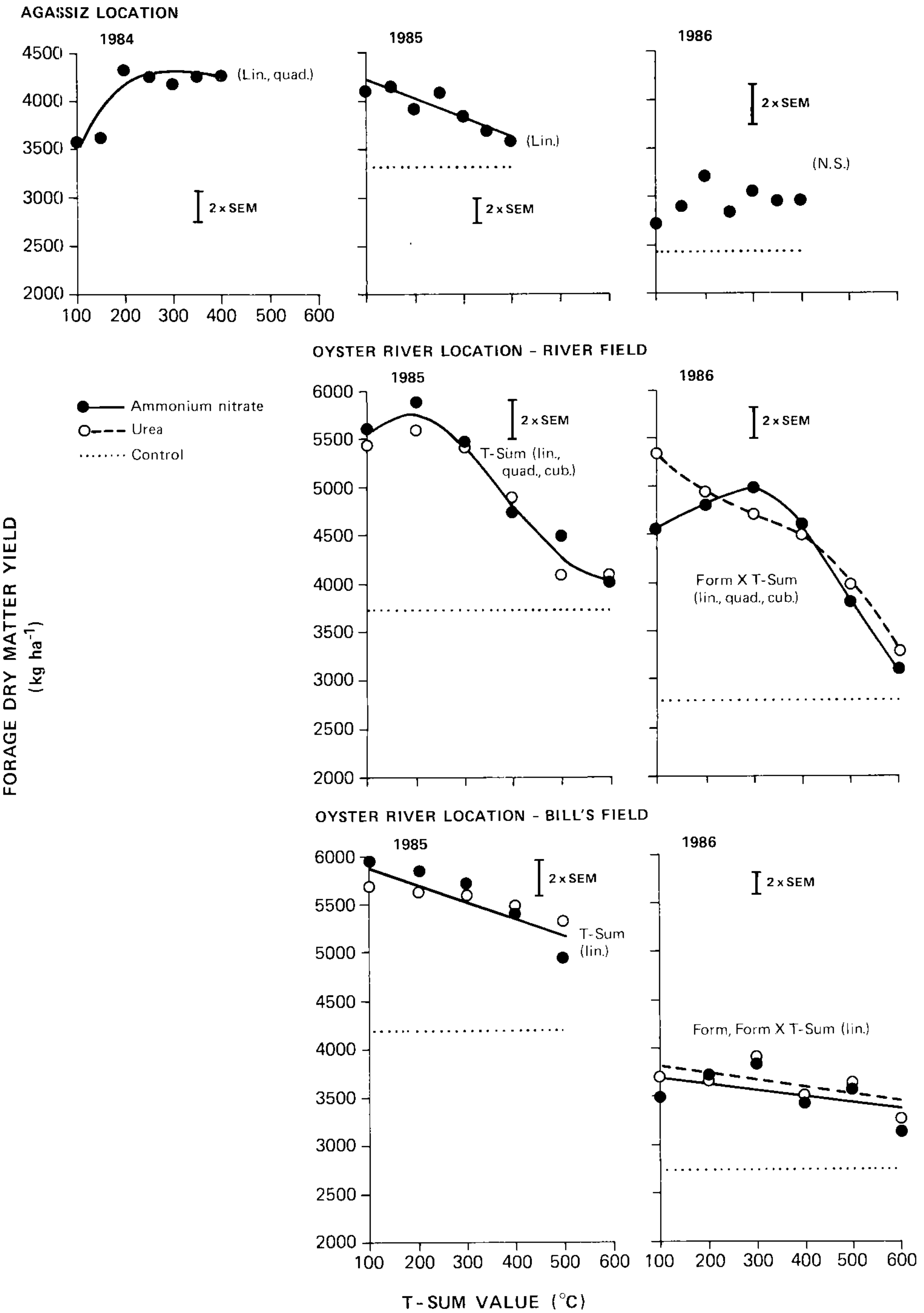


Fig. 2. Dry matter yield of first-cut forage production in response to times of N application as determined by T-sum.

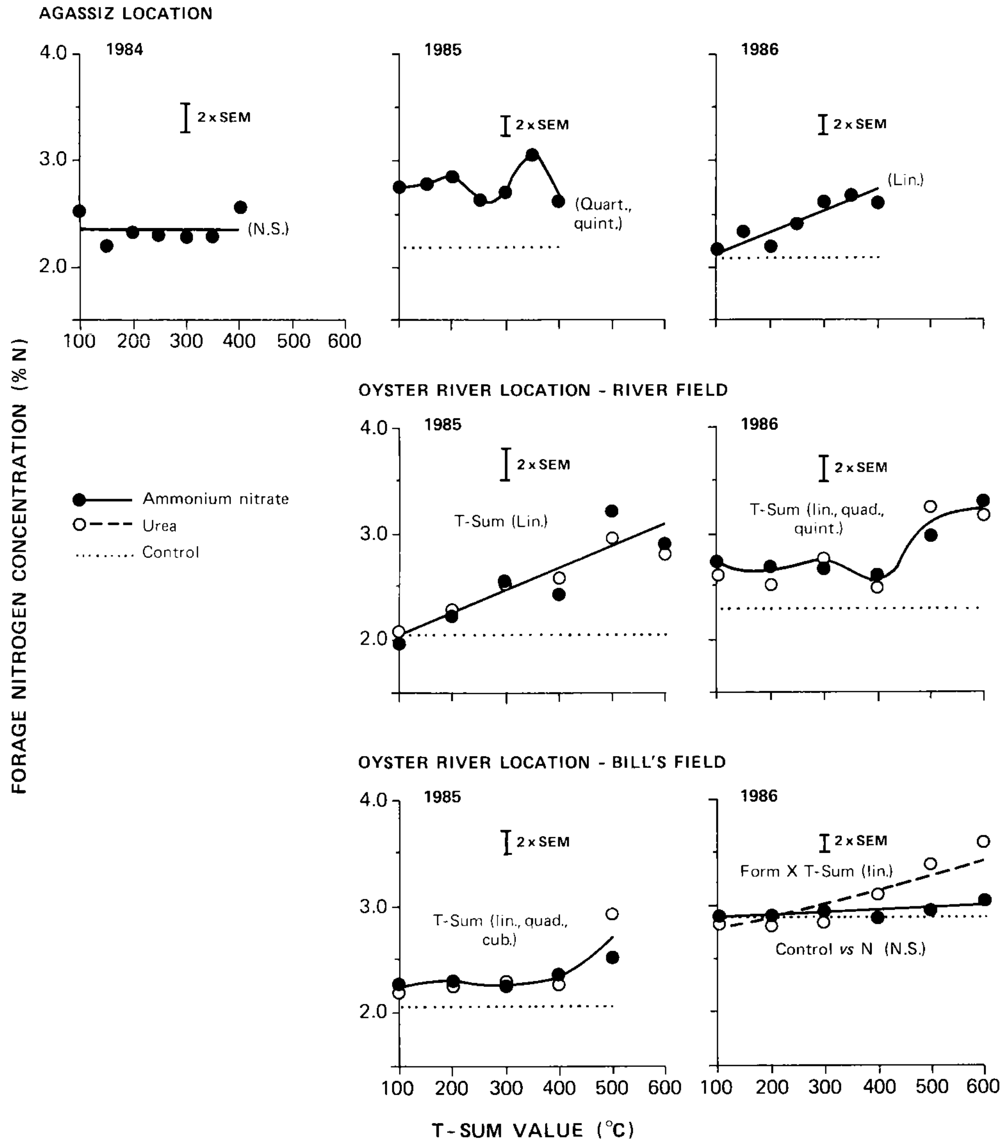


Fig. 3. Concentration of N of first-cut forage in response to timing of N application as determined by T-sum.

cases where a control was included, there were increases in forage dry matter yield in response to the application of N.

Form of N application had an effect in 1986 on both fields at Oyster River as shown by a significant interaction of fertilizer form and application time (Fig. 2). This was not the case in 1985. At the River field site, the form × T-sum interaction was curvilinear and at Bill's field, it was linear. The effect of form of N was quite small with an overall advantage with urea. For example, in the case of

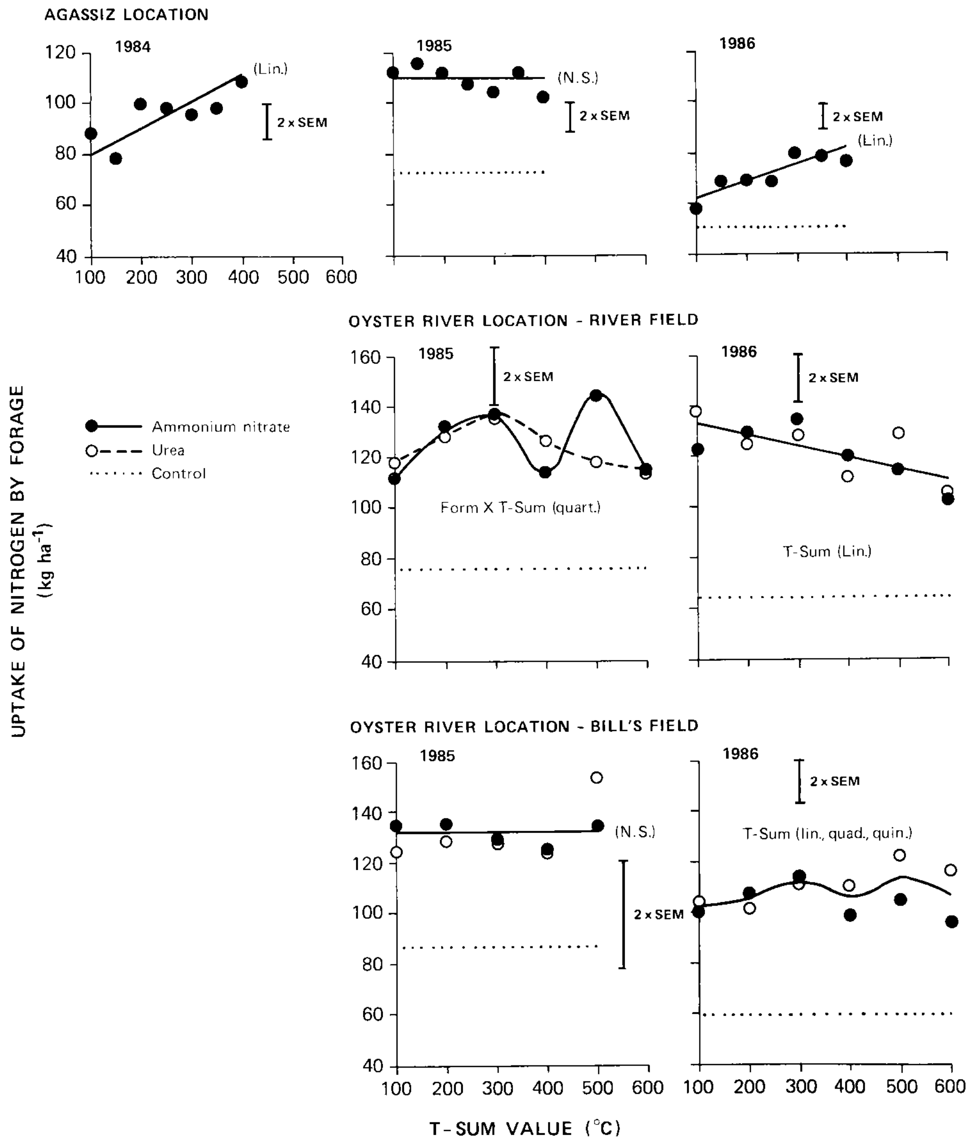


Fig. 4. Uptake of N by first-cut forage in response to times of N application as determined by T-sum.

Bill's field in 1986 where form main effect was significant, the average dry matter yield from N applications at all T-sums was 3600 kg ha^{-1} for urea and 3535 kg ha^{-1} for ammonium nitrate.

The application of N at various T-sums influenced the concentration of N in the plant in all but one of the trials (Fig. 3). Where there was an effect, the trend (which was both linear and curvilinear) was for higher N concentration as N was applied later in the season. In all but one (Bill's field in 1986) of the six trials where a control treatment was included, the application of N increased the concentration of N in the plant. In Bill's field in 1986, however, there was a significant interaction between form of N application and T-sum of a linear form. In that case, urea tended to result in higher N concentration as the application was made later in the season.

Accumulation of N in aboveground parts of the plant was influenced by time of application in five of the seven trials (Fig. 4). The responses were not consistently linear, with some trials showing a general increase in uptake as N was applied at higher T-sums, others showing a decrease, while the rest fluctuated randomly. One trial (River field in 1985) had a significant form × T-sum interaction. The response to the two forms was curvilinear and no one form appeared to be particularly advantageous overall for increasing total N yield. In the six trials where a control was included, there was a substantial overall increase in N uptake with N application.

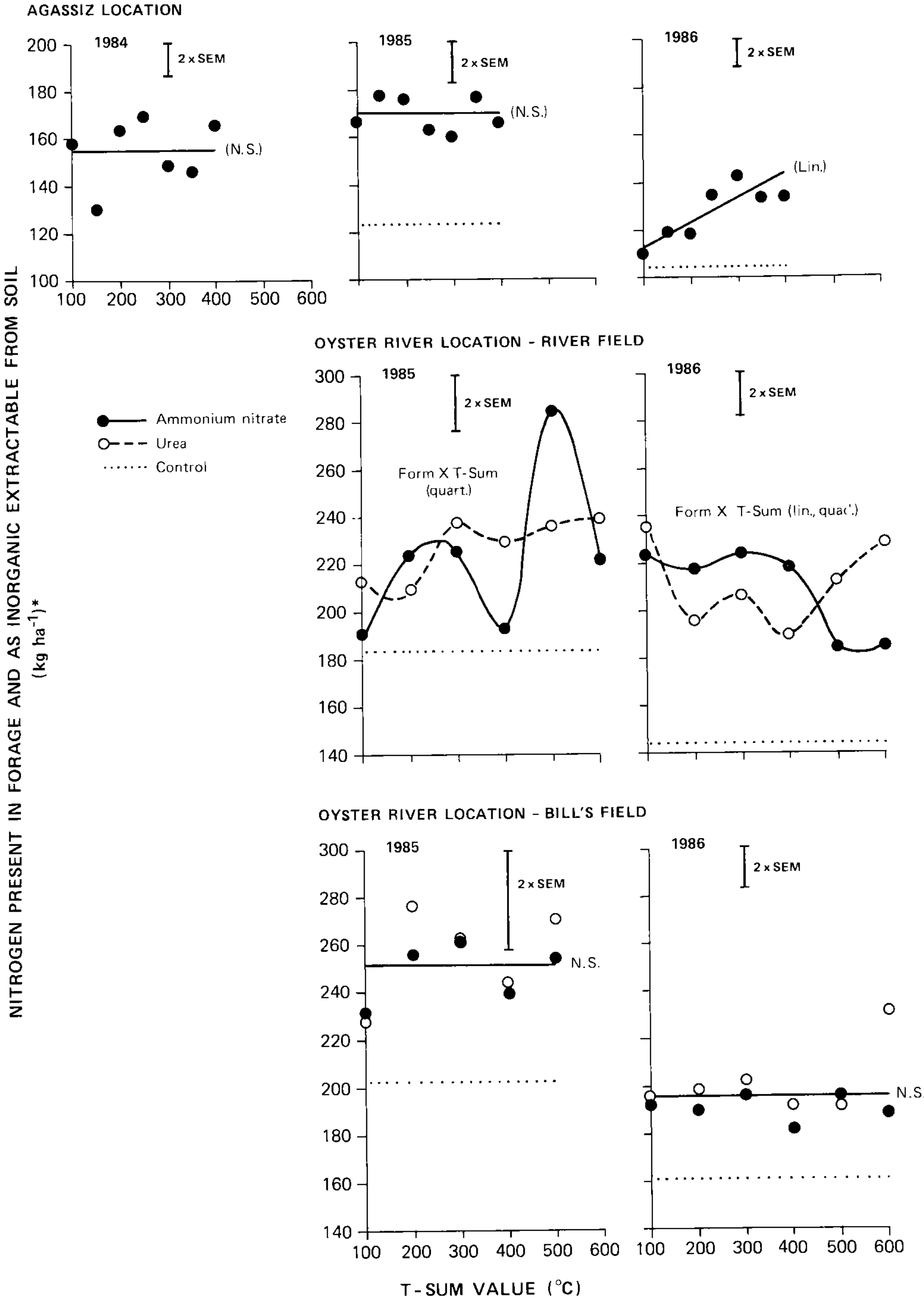
Total recovery of N in the aboveground parts of the plant and as inorganic N ($NO_3^- + NH_4^+$) extractable from the soil to a depth of 0.60 m (0.30 m at Oyster River in 1985) varied with time of N application in three of the seven trials (Fig. 5). In one of the trials (Agassiz 1986), there was a linear increase in N recovery as N was applied later in the season. In the other two trials (River field 1985 and 1986), the response was curvilinear, with different responses to the form of fertilizer N applied. There was no consistent increase or decrease in response to time of application. There did not appear to be a consistent advantage to recovery for either of the forms of N applied. In all six cases where a control was included, a larger amount of N was recovered in the N treatments than in the control treatments but, in general, the increased recovery (as determined by the difference between N and no N treatments) was less than the 100 kg N ha^{-1} initially applied.

In most cases, soil-extractable inorganic N was similar (N application vs. control significant) for the control and the N-treated plots (Fig. 6). In four of seven trials, the amount of soil-extractable N in the profile sampled after the first-cut did not differ in response to the time N was applied. In the other three trials, the soil, extractable N showed a curvilinear but overall inconsistent trend with time of application and form of fertilizer applied. An examination of the vertical distribution of N in the soil profile sampled suggested little if any relative movement of N applied at various times, even at the Agassiz location in 1986 where considerable rain fell between T-200 and T-250. Ammonium tended to be the dominant form of N extracted from the soil and accounted for 68 to 99% of the inorganic N. Nitrogen in the urea form was not detected and room temperature incubation trials showed the 100 ppm urea N was hydrolyzed within 3d in soils from both Oyster River locations.

Extractable inorganic N measured just prior to fertilizer applications at various dates according to T-sum accumulations varied curvilinearly in all of the trials but no consistent trends were obvious (Fig. 7). As was found for the soil analyses after harvest, the dominant form of N was ammonium. Clay fixed ammonium was detected at both Agassiz (195–208 kg N ha^{-1} to 0.15 m) and Oyster River (46–60 kg N ha^{-1} to 0.15 m). Both soils showed the potential for fixing NH_4^+-N in a laboratory recovery evaluation with the soil at the Agassiz location fixing about 26% and Oyster River about 15% of 100 ppm added. Analytical methods were not adequate to evaluate changes in fixed NH_4^+ in response to N added at different times (Kowalenko 1987b).

The time of N application according to T-sum influenced other nutrient concentrations in the forage (K, Mn, Ca, P, Mg and Zn) at Agassiz where these measurements were

Fig. 5. Nitrogen recovered in the forage as total above ground plant uptake and in the soil profile* as extractable inorganic N in response to times of N application as determined by T-sum at first cut. (*Soil extraction determined to 0.30-m depth at Oyster River fields in 1985 and all others to 0.60-m depth.)


AGASSIZ LOCATION
1984
1985
1986
2 x SEM
(N.S.)
(Lin.)
OYSTER RIVER LOCATION - RIVER FIELD
Form X T-Sum (quart.)
Form X T-Sum (lin., quad.)
OYSTER RIVER LOCATION - BILL'S FIELD
N.S.
Ammonium nitrate
Urea
Control
NITROGEN PRESENT IN FORAGE AND AS INORGANIC EXTRACTABLE FROM SOIL (kg ha-1)*
T-SUM VALUE (°C)

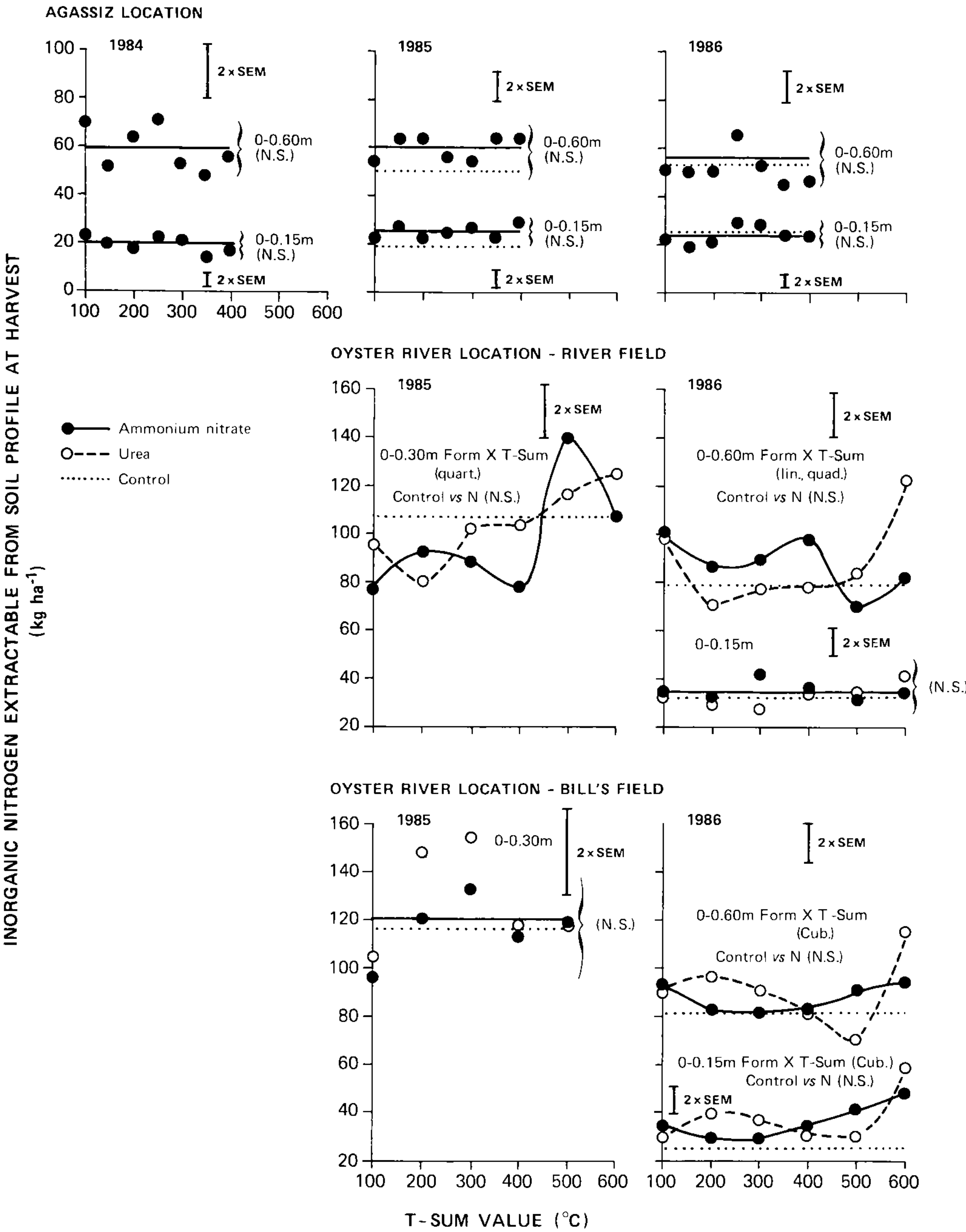


Fig. 6. Inorganic N extracted from the soil profile at first-cut crop harvest in response to N application as determined by T-sum.

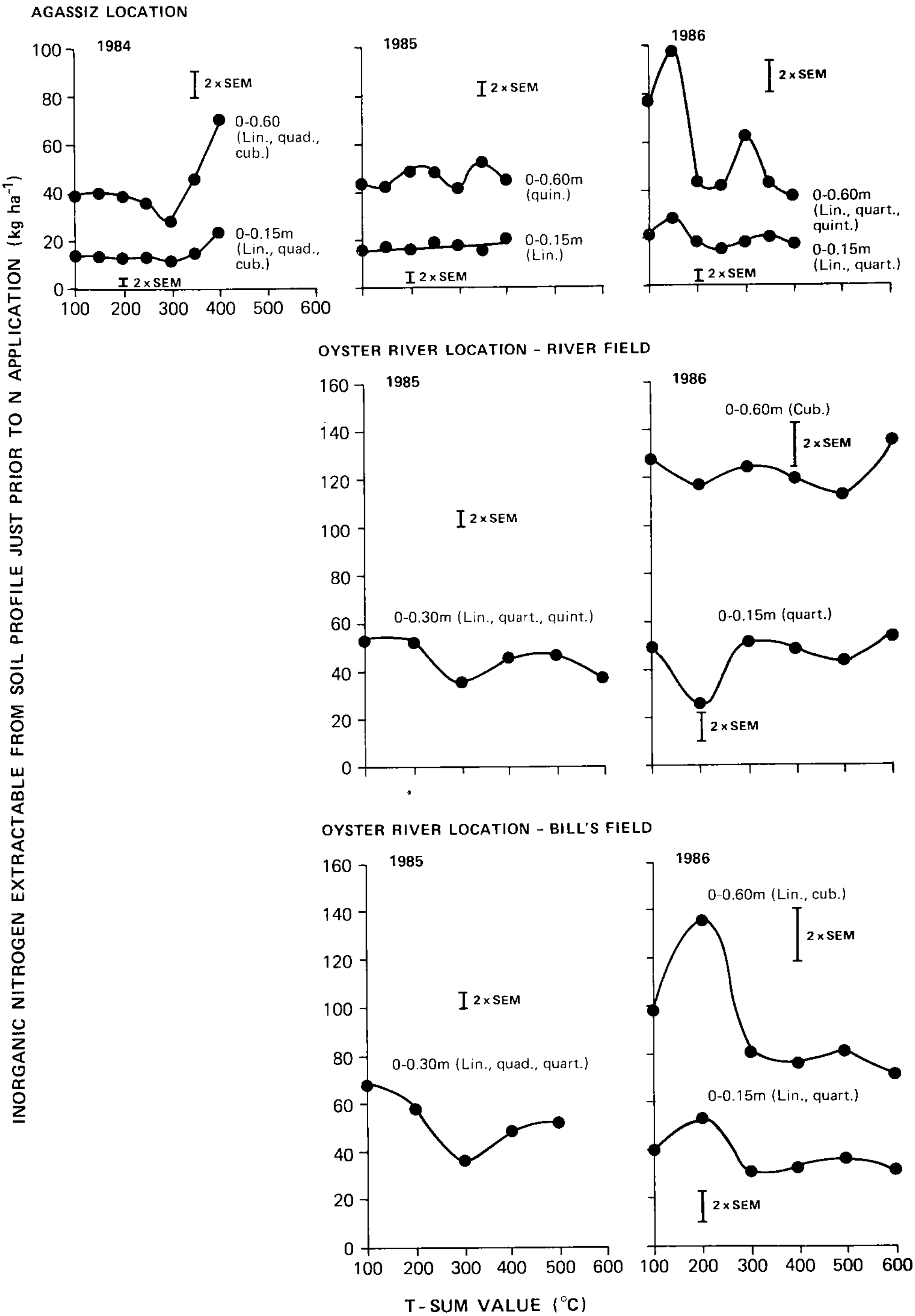


Fig. 7. Inorganic N extracted from the soil profile just prior to N application at various T-sum times.

made, but the effect was not consistent from year to year (data not shown). Other quality measurements (ADF, TDN, Cu, Fe and Na) were not affected by N application at various T-sums in any of the 3 yr. Only Mg was increased by N applications compared to the control in both years at Agassiz when a control was included whereas K and Mn were not affected in either year. Although some of the other quality measurements were affected in 1985 the effect was not observed in 1986 and hence not reported.

Time of early spring N application had a residual effect on forage yield of the second cut at Oyster River (Table 1). The form of the applied N had no effect and the later the N was applied the higher was the second cut yield. Total N content was not affected significantly by the residual N. At Agassiz, the yield of subsequent cuts was significantly influenced by the time of N applied in the spring even though 75 kg N ha^{-1} was applied after the first cut. No consistent pattern was evident, and data are not presented.

Long-term (50 yr) weather records at Agassiz show that T-sum 200 has occurred as early as 27 Jan. and as late as 26 Mar. with a simple mean date of 25 Feb. Comparable weather data at Agassiz and Oyster River from 1983 to 1987 showed that T-sums vary between locations and from year to year. The average Julian day at which T-sum 200 was reached at Agassiz was 45 whereas it was 53 at Oyster River. During that 5-yr period, the date at which T-sum 200 occurred differed by 1–22 d between the two locations.

Table 1. Residual effect of spring N application timed by T-sum on yield of second-cut forage at Oyster River

	1985		1986	
T-sum	River field	Bill's Field	River field	Bill's field
	kg ha^{-1}			
100	2860	4210	950	890
200	2960	4100	970	900
300	3080	4090	1030	880
400	3290	4010	980	890
500	3660	4600	1170	940
600	3960	—	1190	1060
SEM	130	100	40	30
Significance	Lin., quad.	Lin., cub., quart.	Lin., quint.	Lin., quad.

DISCUSSION

The results of the field study conducted over 3 yr and at two widely spaced locations in south coastal British Columbia showed that early application of N usually but not always resulted in greater dry matter production of first-cut forage than later applications. Leaching, as shown by similar distributions and amounts of extractable N in the soil profile for all times of N application within each trial, did not appear to be a problem with early application. The quality of the forage (assessed by N uptake) responded in the opposite way, with generally increased plant N concentration as the N was applied later in the season. Although these results were not consistent in every trial, they did occur in a majority of cases. This is in agreement with results reported in Scotland in that the T-sum method should be considered useful but not an "exact science" (Harkess 1983; Swift et al. 1985). Many factors could contribute to the variation in yield responses to timing of application including weather (temperature and rainfall), management practices (time of harvest, etc.) as well as random variability.

Weather data showed that occurrence of temperatures sufficiently warm for initiation of forage growth (T-sum 200) varied widely from year to year (range of 57 d) and that differences of almost a month can occur from one location to another in the same year in south coastal British Columbia. Previous research suggested that there is considerable risk for nitrate leaching in early spring (Kowalenko 1987b). The results of the T-sum study, coupled with a desire for maximum forage production, the concern about nitrate leaching and the variable warming rate in the spring in south coastal British Columbia, show that N application according to T-sum would be better than suggesting a specific calendar date as in Northern Ireland (Gracey 1987).

Since T-sum can be readily measured, N fertilization should not be done very much earlier than a T-sum of 200 for maximum dry matter yield. This practice should also minimize possible nitrate leaching. Application could even be delayed if higher protein but not necessarily high dry matter yield is desired. Application of N according to T-sum 200 was generally earlier than what was used in previous N fertilization trials where applications were in mid March to April (Bomke and Bertrand 1983; Maas et al. 1962; Maynard and Bomke 1980) which is currently practiced by most growers. Since there was very little difference in response to form of N applied, the cost of the fertilizer would be the prime consideration for economical production. However, Bomke and Bertrand (1983) found a slight advantage for total year grass yields when split applications of ammonium nitrate were made. Application of N at different times may result in differences in the rate of crop maturation and may account for some of the differences in yield and N content.

The precise reason for the occasional lower yields when N was applied earlier than T-sum 200 cannot be determined with available non-tracer measurements. Increased leaching of early application of N did not appear to be very significant since profile extractable inorganic N was quite similar after first cut for all times of spring application. The presence of a majority of the inorganic N in the ammonium form would probably contribute to limiting the amount of N movement. Although the cool soil temperatures early in the growing season appear to have restricted nitrification of ammonium, hydrolysis of urea was apparently sufficient for the plant growth that occurred. The response of the crop to very early N applications such as at T-sum 100 may have been influenced by competition for N by plant roots and soil microorganisms. A flush of microbial activity may occur more quickly than plant root activity as soil temperatures start to increase in the spring, resulting in a competitive advantage to the microorganisms at that time. The advantage would reduce as soil and air temperatures increase and crop growth accelerates.

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