NUTRIENT MOVEMENT IN A SANDY LOAM FOREST NURSERY SOIL AT PRINCE ALBERT, SASKATCHEWAN

BY

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ABSTRACT

Soil water samplers were used to collect leachate from fertilized and irrigated fields at the Prince Albert Forest Nursery over four growing seasons. Leachate samples were analyzed for nitrate, phosphorus, potassium, calcium, and magnesium to assess movement of these nutrients.

The order of nutrient loss through leaching was Ca > NO_3 > Mg > K > P in seedbeds and in a transplant field it was Ca > Mg > NO_3 > K > P. Losses of Ca and Mg were related to their previous levels in the soil. Nitrate loss was greatest in fallowed land, intermediate during the first year of cropping, and lowest after establishment of the crop. Losses of P and K by leaching were negligible after the first crop year. Recommendations include the proper rate and method of fertilization and irrigation for minimizing nutrient losses.

RESUME

Durant quatre saisons de croissance, on a utilisé des échantillonneurs d'eau dans le sol pour recueillir les solutums dans des champs fertilisés et irrigués a la pépinière forestière de Prince Albert. Ces solutums furent analysés quant à leur teneur en NO_3, P, K, Ca et Mg afin d'évaluer le mouvement de ces agents nutritifs.

Voici, en ordre, la perte en agents nutritifs par le lessivage: Ca > NO_3 > Mg > K > P dans les lits de germination. Dans les stations de repiquage, l'ordre était comme suit: Ca > Mg > NO_3 > K > P. Les pertes de Ca et de Mg dépendaient de leur teneur antérieure dans le sol. La perte de nitrate fut la plus élevée sur le terrain en jachère; elle s'avéra moyenne au cours de la première saison de récolte et la plus faible après l'établissement de la récolte. Le P et le K connurent peu de pertes dues au lessivage après la première année de récolte. L'auteur recommande entre autres un taux et une méthode propices de fertilisation et d'irrigation pour diminuer les pertes d'agents nutritifs.

CONTENTS

INTRODUCTION

Most studies of nutrient loss by leaching have been conducted in an agricultural context and were done to measure and explain losses of various nutrient ions following the application of fertilizers. Khonke *et al.* (1940), Bates and Tisdale (1957), and Logan and McLean (1973) reported that leaching losses were increased by coarse texture and a porous crumb structure. Levin (1964) and Gardner (1965) found that the depth to which nutrients were leached depended on field capacity of the soil (on a volume basis) and on the amount of leaching water. Among the anions, nitrate (NO_3) and chloride (Cl) were leached readily from the soil: the amount lost was closely related to the quantity in the soil and the amount of percolate (Richards and Wadleigh 1952). Movement of NO_3 was also greater in soils with low cation exchange capacity (CEC), low iron and aluminum oxides, and near-neutral pH (Thomas 1970). Sulphate (SO_4) and bicarbonate (HCO_3) were also leachable but to a lesser extent. Normally, the phosphate ion (PO_4, HPO_4, or H_2PO_4, depending on pH) is one of the least mobile and is usually present only in small amounts in leachates. Among the cations, calcium (Ca) and magnesium (Mg) are generally the highest in leachate. Potassium (K) may be low in leachate from some soils because of chemical fixation by certain clay minerals. Sodium (Na) is readily leached because of its relatively low energy of retention on the exchange complex; it is therefore low in soils that developed under well-drained, nonsaline and nonalkali conditions.

Forest nurseries are generally located on coarse- to medium-textured soils because these facilitate root growth, soil management, and nursery operations. Since they have low CEC and available water capacity (AWC), they are fertilized and irrigated frequently during the growing season. Therefore, the potential for nutrient loss through leaching is great. Leaching of K in the absence of seedlings has been studied in an Ontario forest nursery (Krause 1965), and nutrient movement within a forest soil has been investigated under field and laboratory conditions (Cole and Gessel 1963, Rains and Bledsoe 1976). However, no leaching studies have been done in a prairie nursery. This investigation was undertaken to determine, under operational conditions of fertilization and irrigation, the nature and magnitude of nutrient movement through a forest nursery soil.

MATERIALS AND METHODS

SITE CHARACTERISTICS

The Prince Albert Forest Nursery, Saskatchewan is located (Lat. 53°13', Long. 105°41') within the Mixedwood Section (B 18a) of the Boreal Forest Region (Rowe 1972). Mean elevation at the nursery is 431 m. Lowest monthly mean temperature is -21.1°C (January), and the highest is 17.5°C (July). Mean annual precipitation is 392 mm, 64% of which occurs during the period May to September (Environment Canada 1972). The average frost-free period is 112 days.

The soils are Dark Gray Chernozems that have developed on moderately coarse to medium glaciofluvial sands (Mitchell *et al.* 1950). They have a thick (20-25 cm), dark, neutral, sandy loam Ap horizon that is underlain by an alkaline, sandy Bm and a calcareous C horizon (Edwards 1977). Three fields, Nos. 12, 40, and C-14 (Figure 1), were selected as representative of seedbed, transplant, and recently cleared areas respectively. Depth to the water table varied from 90 cm to 130 cm. Certain soil characteristics in these fields are shown in Table 1.

FIELD TREATMENTS

For each of four growing seasons (1972-75), the fields were cropped with either jack pine (*Pinus banksiana* Lamb.) or white spruce (*Picea glauca* (Moench) Voss), fertilized, and irrigated with water from the Little Red River (Figure 1). Precipitation at the nursery during May to September of each year was recorded (Table 2). Crop sequence and total precipitation plus irrigation are in Table 3.

Irrigation was by overhead system using "Rain Bird" Model 29 sprinklers with lateral lines (7.5 cm diam.) set 15 m apart. Each lateral had 60-cm risers that were spaced at 9 m, and each riser was equipped with a 3.5-mm nozzle that delivered water at 20 dm^3/min at an operating pressure

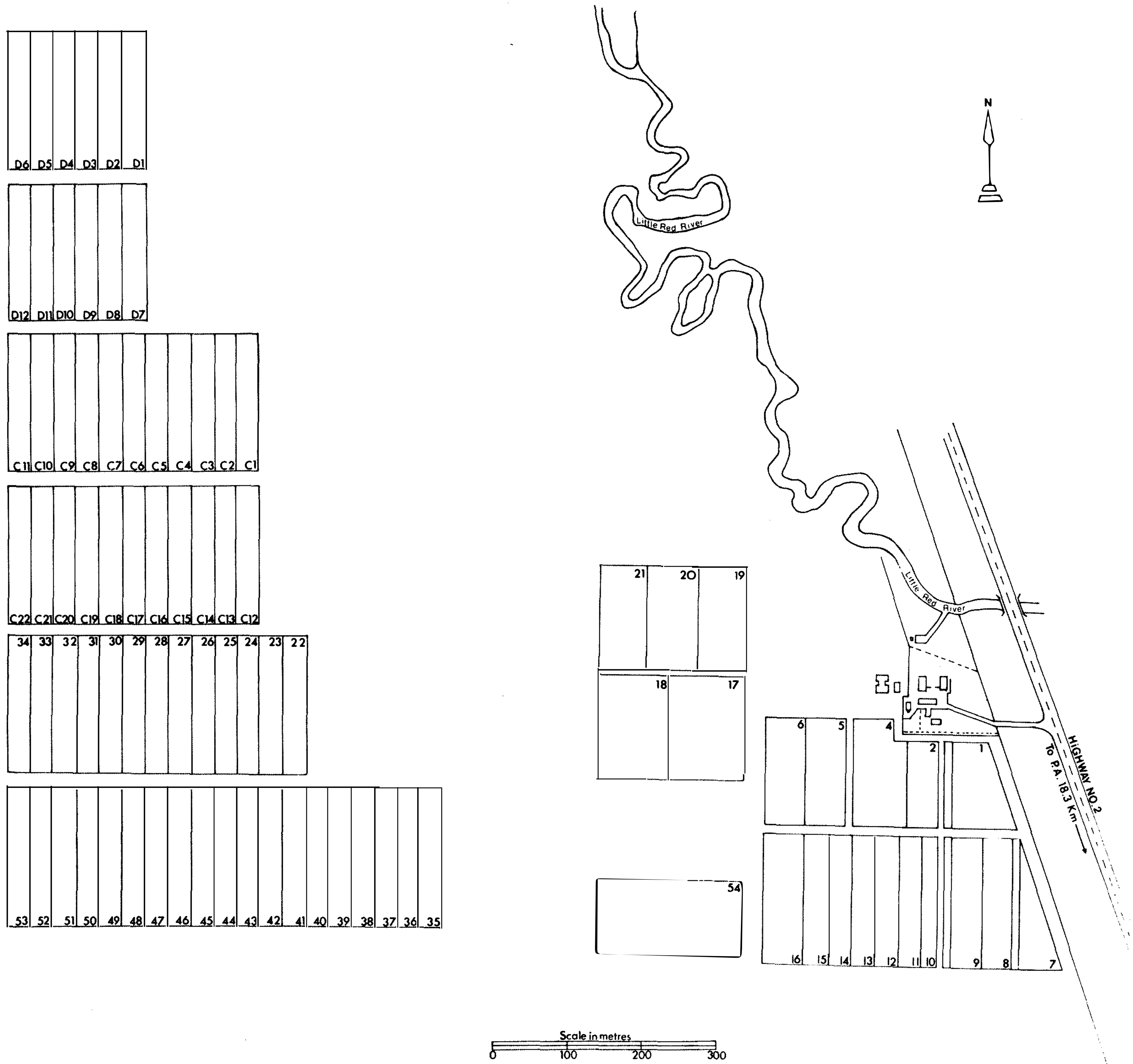

Figure 1. Field layout of the Prince Albert Forest Nursery, Prince Albert, Saskatchewan

Table 1. Soil characteristics of three fields used in the study

Depth cm	Field 12				Field 40				Field C-14			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Texture*	SL	SL	S	S	SL	SL	S	S	SL	SL	SL	SL
pH	7.8	7.7	7.8	7.9	6.5	6.5	6.7	6.7	7.3	7.7	7.6	7.7
EC dS/m	0.24	0.21	0.21	0.17	0.09	0.08	0.06	0.06	1.98	2.00	1.15	1.12
NO_3 kg/ha	18	15	13	11	18	12	8	5	86	73	37	30
P kg/ha	29	19	13	12	30	25	23	19	16	22	11	9
K kg/ha	174	167	139	163	113	100	102	95	253	244	243	237
Ca kg/ha	7140	2951	1764	1484	2744	3976	1540	5544	7560	2324	1820	1764
Mg kg/ha	762	423	283	197	283	526	165	137	890	330	322	361
CEC me/100 g	18	8	5	4	7	11	4	4	21	7	6	5
$CaCO_3$**	-	-	-	-	-	-	-	+	+	+	+	+

* SL: sandy loam, S: sand

** Free $CaCO_3$: absent "-", present "+"

Table 2. Precipitation (mm) at the Prince Albert Forest Nursery, Saskatchewan during May to September of 1972-75

Date	Year 1972	1973	1974	1975	1941-71 Monthly Mean*
May	13	27	64	40	35
June 7	10	94	6	34	
14	20	16	10	2	
21	3	21	-	15	
30	10	75	52	33	
June Total	43	206	68	84	61
July 7	14	59	6	14	
14	27	8	80	-	
21	11	10	12	11	
31	3	25	4	10	
July Total	55	102	102	35	66
Aug. 7	2	6	41	10	
14	27	11	78	14	
21	5	tr	19	10	
31	-	19	15	18	
Aug. Total	34	36	153	52	52
Sept. 7	-	-	10	9	
14	8	53	32	1	
21	37	-	2	-	
30	2	10	8	5	
Sept. Total	47	63	52	15	35
Grand Total	192	434	439	226	249

* The mean precipitation for May to September inclusive, over the 31-year period, 1941 to 1971, is 249 mm.

Table 3. Crop sequence and total precipitation (P) plus irrigation (I) applied to the study areas over four growing seasons, 1972-75

Field No.	1972 Crop	1972 P + I Total mm	1973 Crop	1973 P + I Total mm	1974 Crop	1974 P + I Total mm	1975 Crop	1975 P + I Total mm
12	1-0 Jack Pine	464	2-0 Jack Pine	454	3-0 Jack Pine	439	Fallow	226
40	1-0 Jack Pine	447	2-0 Jack Pine	454	3-0 Jack Pine	439	Fallow	226
C-14	2-1 White Spruce	391	2-2 White Spruce	434	Fallow	439	Fallow	226

of 414 kPa. Under these conditions, the application rate was approximately 7 mm/h. The beginning and end of each irrigation period depended on visual observation of weather and soil conditions by nursery personnel.

Fertilizers were the usual commercial grades used at the nursery (Table 4). They were plowed in prior to seeding and transplanting, but where the crop was already established they were broadcast and watered into the soil surface.

LEACHATE COLLECTION

Tubular soil water samplers[1] were used to collect leachate samples. Prior to installation, the ceramic cup of each sampler was washed with dilute hydrochloric acid (0.01 N) for 24 h, then rinsed free of chloride with distilled water until water quality was unchanged after passing through it. Samplers were installed in each field to depths of 30 and 60 cm from June to October each year for the period 1972-75. Following installation, the samplers were fitted with suitable rubber stoppers, subjected to a tension of approximately 33 kPa with a hand pump, and clamped shut (Figure 2a). Each week thereafter until the end of the growing season, samplers were emptied of leachate using copper tubing, a 500-ml suction flask, and a hand pump (Figure 2b), then tension was reapplied, and the tubing was reclamped. Leachate samples were measured and poured into polyethylene bottles and refrigerated until analyzed.

LEACHATE ANALYSIS

The leachates obtained in 1972 were analyzed only for NO_3-N, P, and K. Ammonium nitrogen (NH_4-N), the N source in some fertilizers, was not determined because ammonium is oxidized to nitrate under normal soil conditions, and nitrate is the form generally found in the soil solution (Thomas 1970). In subsequent years, Ca and Mg, which are not usually applied to nursery soils, were determined to assess their relative movement. Chloride (Cl) was applied as a constituent of potash (KCl)

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[1] Available from Soil Moisture Equipment Corp., Santa Barbara, California. Each sample consists of a porous ceramic cup (4.8 cm i.d.) cemented to PVC piping of similar diameter and appropriate length.

Table 4. Fertilizer grade and amount of N, P, and K applied to the study areas during 1972-75

Date	Field 12					Field 40					Field C-14				
	Fertilizer Grade†	NH_4	NO_3	P	K	Fertilizer Grade	NH_4	NO_3	P	K	Fertilizer Grade	NH_4	NO_3	P	K
		------ kg/ha -------					------- kg/ha -------					------- kg/ha -------			
							1972								
June 27	-					-					21-0-0	47	0	0	0
	-					-					0-0-62	0	0	0	58**
July 12	11-48-0	12	0	24	0	21-0-0	47	0	0	0	-				
	21-0-0	47	0	0	0	0-0-62	0	0	0	58**	-				
Aug. 2	11-48-0	32	0	62	0	-					-				
Oct. 12	11-48-0	25	0	47	0	11-48-0	25	0	47	0	11-48-0	25	0	47	0
	13-16-0	29	0	16	19	13-48-0	29	0	16	19	13-16-10	29	0	16	19
Total		145	0	149	19		101	0	63	77		101	0	63	77
							1973								
July 14	34-0-0	57	57	0	0	34-0-0	57	57	0	0	34-0-0	28	28	0	0
	11-48-0	25	0	47	0	11-48-0	25	0	47	0	11-48-0	12	0	24	0
	-					-					0-0-62	0	0	0	58**
Oct. 1	11-48-0	25	0	47	0	11-48-0	25	0	47	0	-				
Total		107	57	94	0		107	57	94	0		40	28	24	58
							1974								
July 8	34-0-0	19	19	0	0	34-0-0	19	19	0	0	-				
	11-48-0	6	0	12	0	11-48-0	6	0	12	0	-				
	0-0-62	0	0	0	29*	0-0-62	0	0	-	29*	-				
Oct. 23	34-0-0	19	19	0	0	-					-				
Total		44	38	12	29		25	19	12	29					
							1975								
	-					-					-				

† Fertilizer grade in percentages of N, P_2O_5, and K_2O

* Cl at 14 kg/ha also included

** Cl at 28 kg/ha also included

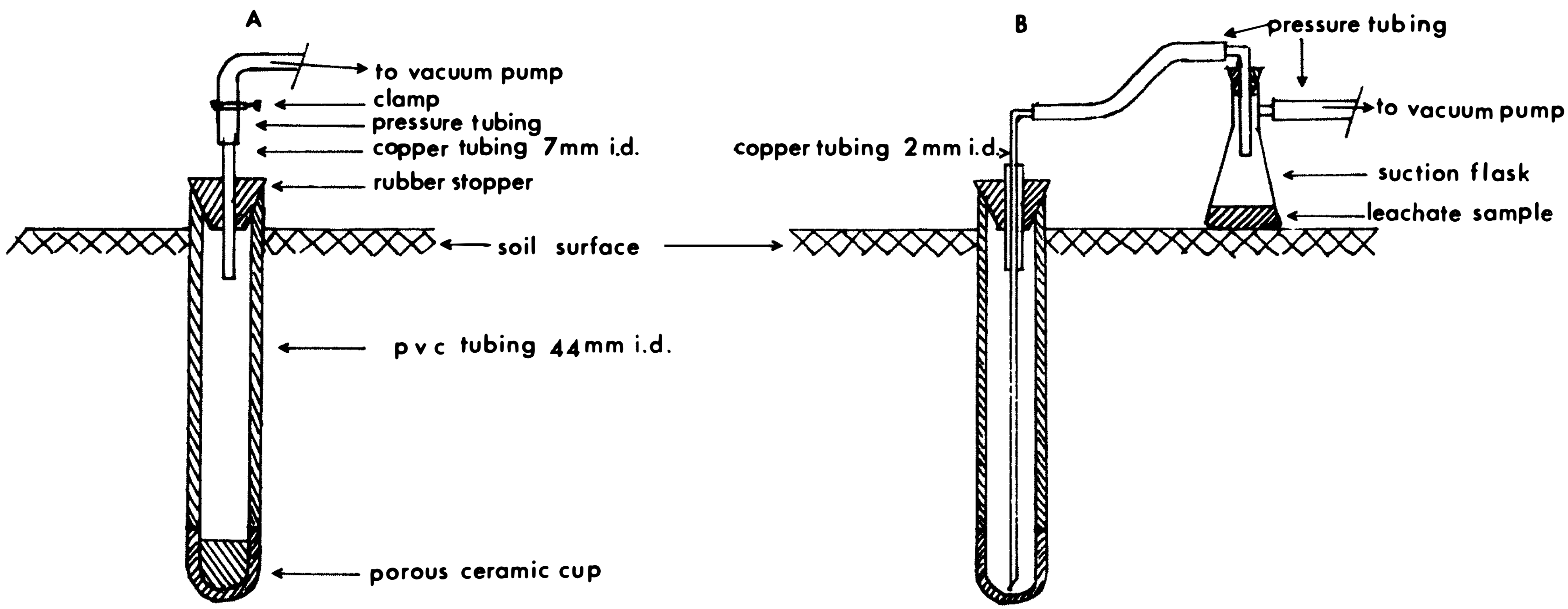

Figure 2. Setup of a water sampler showing (A), position in the soil and (B), collection of leachate

fertilizer; Cl analysis was included in 1974 to compare its pattern of movement specifically with that of NO_3 on fallowed land. Chloride is not strongly held by soil; the portion that is not taken up by plants moves readily with percolating water. Nitrate loss from soil may result from plant uptake, denitrification, and leaching. Therefore, a similar pattern of movement of Cl and NO_3 in the absence of crops would indicate that NO_3 loss was chiefly through leaching.

Nitrate nitrogen (NO_3-N) was determined by the phenoldisulphonic acid method, and Cl by titration with silver nitrate (Jackson 1960). Phosphorus was determined by the ascorbic acid method (Watanabe and Olsen 1965); K, Ca, and Mg were determined by atomic absorption spectrophotometry.

ESTIMATION OF NUTRIENT MOVEMENT

After determining the concentration of each constituent in an aliquot of leachate sample, nutrient movement in the vicinity of each sampler was calculated by multiplying nutrient concentration by the total volume of leachate collected.

RESULTS

NUTRIENT CONCENTRATION IN LEACHATE

The mean concentration of nutrients in leachate samples from 30 and 60 cm within Fields 12, 40, and C-14 are shown in Figures 3, 4, and 5 respectively. When the quality[2] of irrigation water was considered, it was apparent that nutrient concentration in the leachate depended on solution and exchange reactions.

In both seedbeds (Fields 12 and 40) and the transplant area (Field C-14), NO_3 concentration in leachate was much less during cropping than after the crop was removed. During the three crop years 1972-74, average NO_3 concentration at 30 and 60 cm in Field 12 was 24 and 27 mg/ℓ, compared to 60 mg/ℓ at both depths in the fallow year. Similarly, in Field 40, NO_3 at the 30- and 60-cm depths averaged 34 and 39 mg/ℓ during cropping but increased to 111 and 106 mg/ℓ in 1975 after the seedlings

[2] Irrigation water contained on the average 43 mg Ca/ℓ, 11 mg Mg/ℓ, 4 mg K/ℓ, and 8 mg Cl/ℓ. It contained only trace amounts of NO_3 and P.

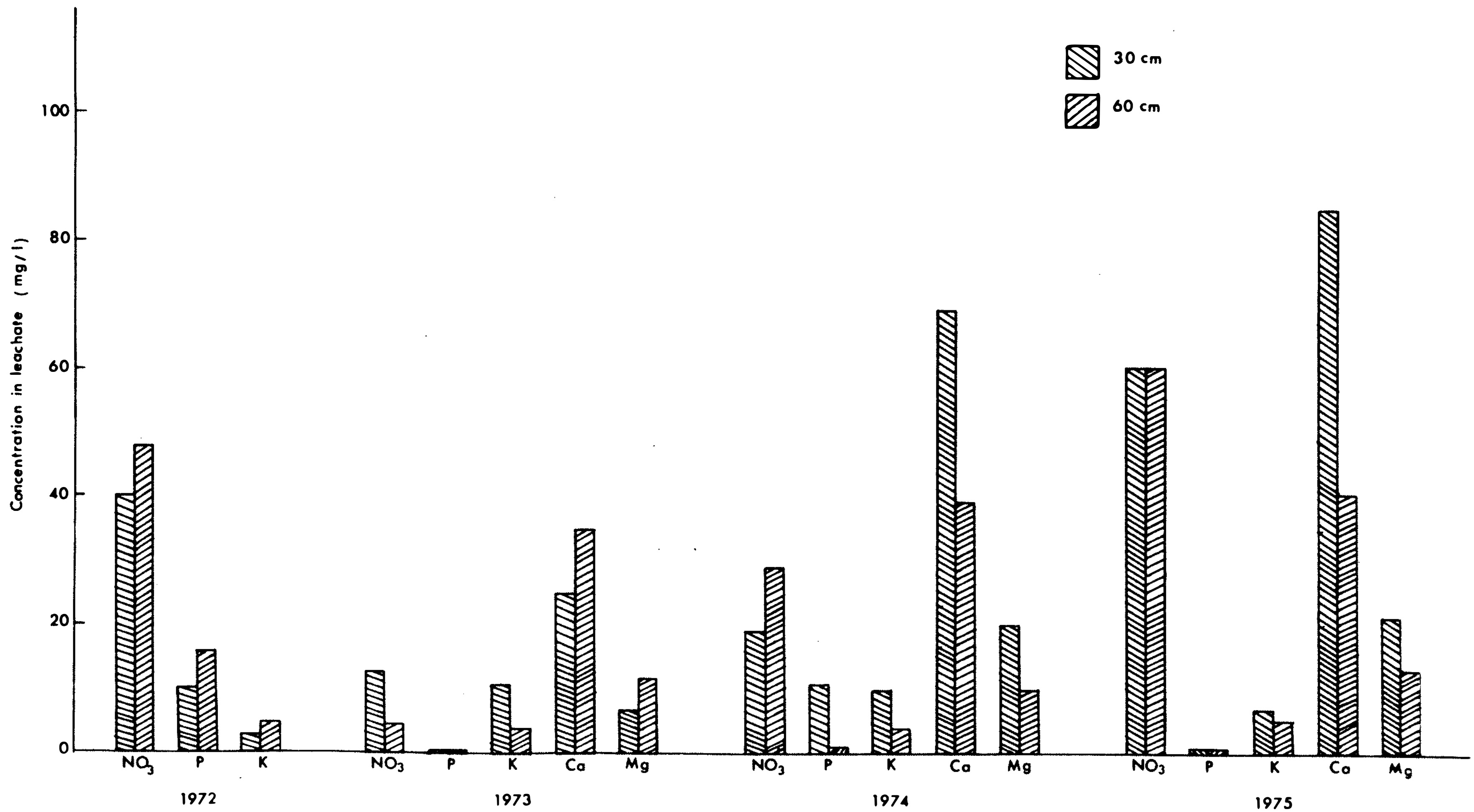

Figure 3. Mean concentration of nutrients in leachate at two depths within Field 12

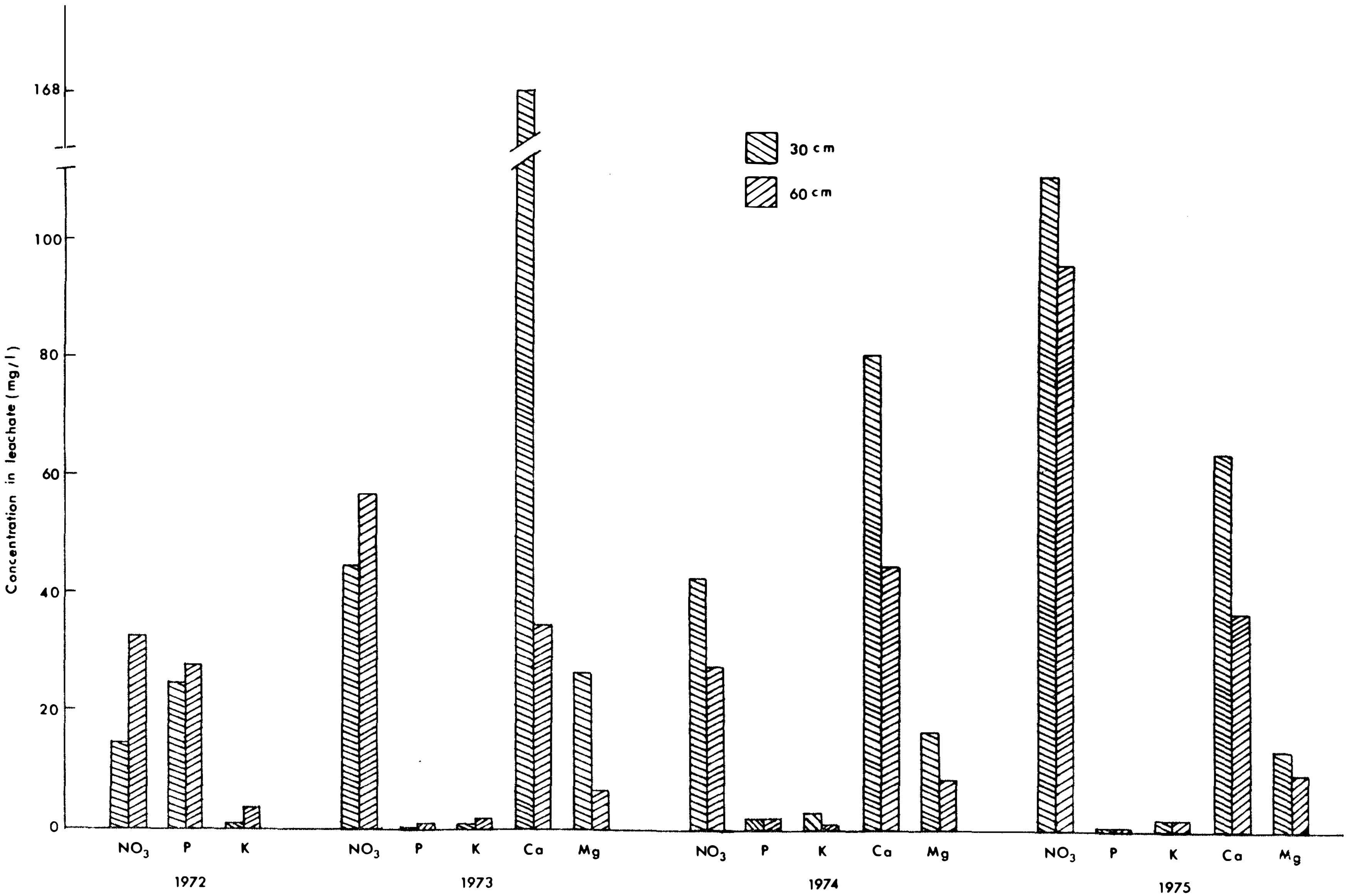

Figure 4. Mean concentration of nutrients in leachate at two depths within Field 40.

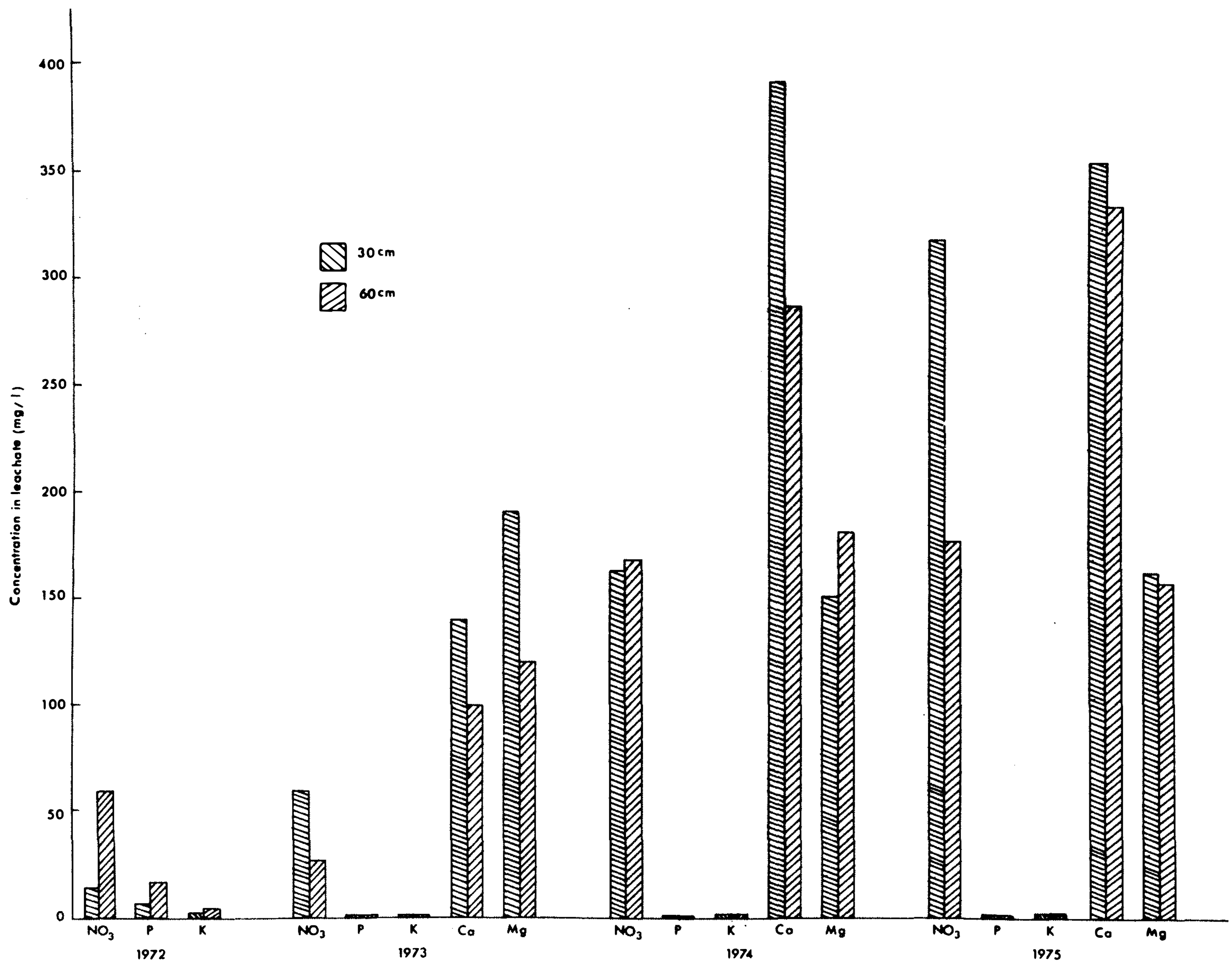

Figure 5. Mean concentration of nutrients in leachate at two depths within Field C-14

were lifted. In the transplant area, changes in NO_3 concentration were even more dramatic, averaging 38 and 44 mg/ℓ at 30 and 60 cm in the presence of transplanted white spruce, but increasing to 239 and 171 mg/ℓ over two subsequent fallow periods.

The mean concentration of P in leachate was highest during the year of seeding or transplanting. However, unlike NO_3, P declined sharply thereafter and remained low in leachate in the following years, including the fallow period. In Field 40, for example, P was reduced from an average concentration of 27 mg/ℓ in 1972 to 0.5 mg/ℓ in 1973 and did not increase significantly in ensuing years. Of all constituents determined, P was lowest in concentration.

Potassium concentration fluctuated the least between years and was the second lowest of the elements determined. In Field 12, mean K concentration at both depths declined from 13 mg/ℓ in 1972 to 6 mg/ℓ in 1975. In the two other fields, K concentration varied only between 1 and 3 mg/ℓ over the 4-year period.

Calcium was the predominant element in leachate collected from all fields. Generally, the concentration at 30 cm was higher and varied more than that at 60 cm. In Field 12, Ca concentration at 30 cm increased from 25 mg/ℓ in 1973 to 69 mg/ℓ in 1974 and 84 mg/ℓ in 1975, but over the same period Ca at 60 cm remained in the 35-40 mg/ℓ range. At 60 cm in Field 40, Ca also remained relatively constant (35-45 mg/ℓ), while at 30 cm it decreased from 168 mg/ℓ in 1973 to 64 mg/ℓ in 1975. In the transplant field, Ca concentration at both depths was consistently higher than the levels found in seedbeds and increased most sharply (2.5 to 3 times) following removal of the crop.

Magnesium concentration, though lower than Ca, followed a similar trend between fields and years. At 60 cm, the concentration of Mg was usually lower than at 30 cm. In both seedbeds, Mg at 60 cm remained within a fairly narrow range of 8-12 mg/ℓ, whereas at 30 cm the concentration fluctuated more widely, increasing from 7 to 21 mg/ℓ in Field 12 and decreasing from 27 to 14 mg/ℓ in Field 40 between 1973 and 1975. In the transplant area, Mg concentration was higher and changed only slightly between cropped and fallow conditions. At 30 cm, Mg in leachate decreased from 190 mg/ℓ under 2-2 white spruce to an average of 155 mg/ℓ after the crop was lifted, but at 60 cm the concentration increased from 120 to 165 mg/ℓ.

NITRATE-CHLORIDE COMPARISON

Since Cl is not adsorbed on the exchange complex of soil nor subject to biological transformation, it is leached from the soil with relative ease. If NO_3 concentration was controlled only by the volume of percolate, then the pattern of movement of both NO_3 and Cl on fallowed land should be similar. Results indicated that this was the case only under certain conditions. Concentrations of NO_3 and Cl in the soil solution were strongly correlated ($r = 0.8$) during the second year of fallow (Figures 6 and 7, Field C-14) but not the first. Nitrate concentration was always greater than Cl, but in the first year of fallow (1974 for C-14; 1975 for Fields 12 and 40) the relationship was weaker ($r = 0.5$).

NUTRIENT CONTENT OF LEACHATE

Total nutrient content of the leachate in each sampler is shown in Table 5. The volume of leachate collected at 60 cm was usually larger than that at 30 cm, and therefore in most cases, regardless of nutrient concentration, larger amounts of nutrients were retained by the deeper samplers. More NO_3, Ca, and Mg were collected at both depths within the transplant field than in either seedbed area; and among the latter, levels of these nutrients were higher in Field 40 than in Field 12. In the seedbeds, constituents were removed at both depths in the following order: $Ca > NO_3 > Mg >> K > P$, whereas in the transplant field the order was $Ca > Mg > NO_3 >> K > P$. On the average, more NO_3 moved during the fallow period than during cropping, whereas the amounts of Ca and Mg collected in a particular field were similar under either condition. Sigificant movement of P and K occurred mostly in the initial year of cropping.

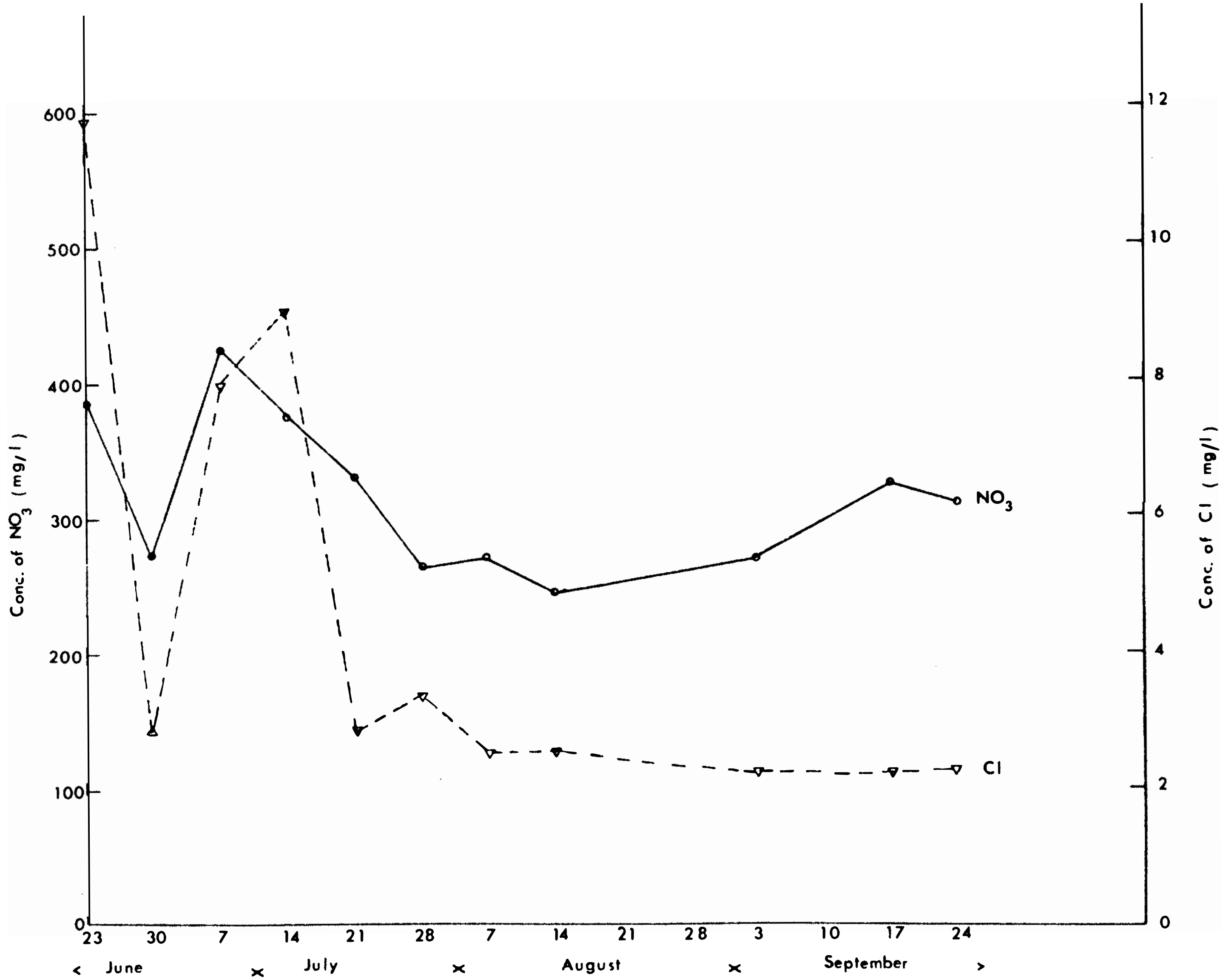

Figure 6. Concentration of NO_3 and Cl in Field C-14 at 30 cm during 1975 (r = 0.80)

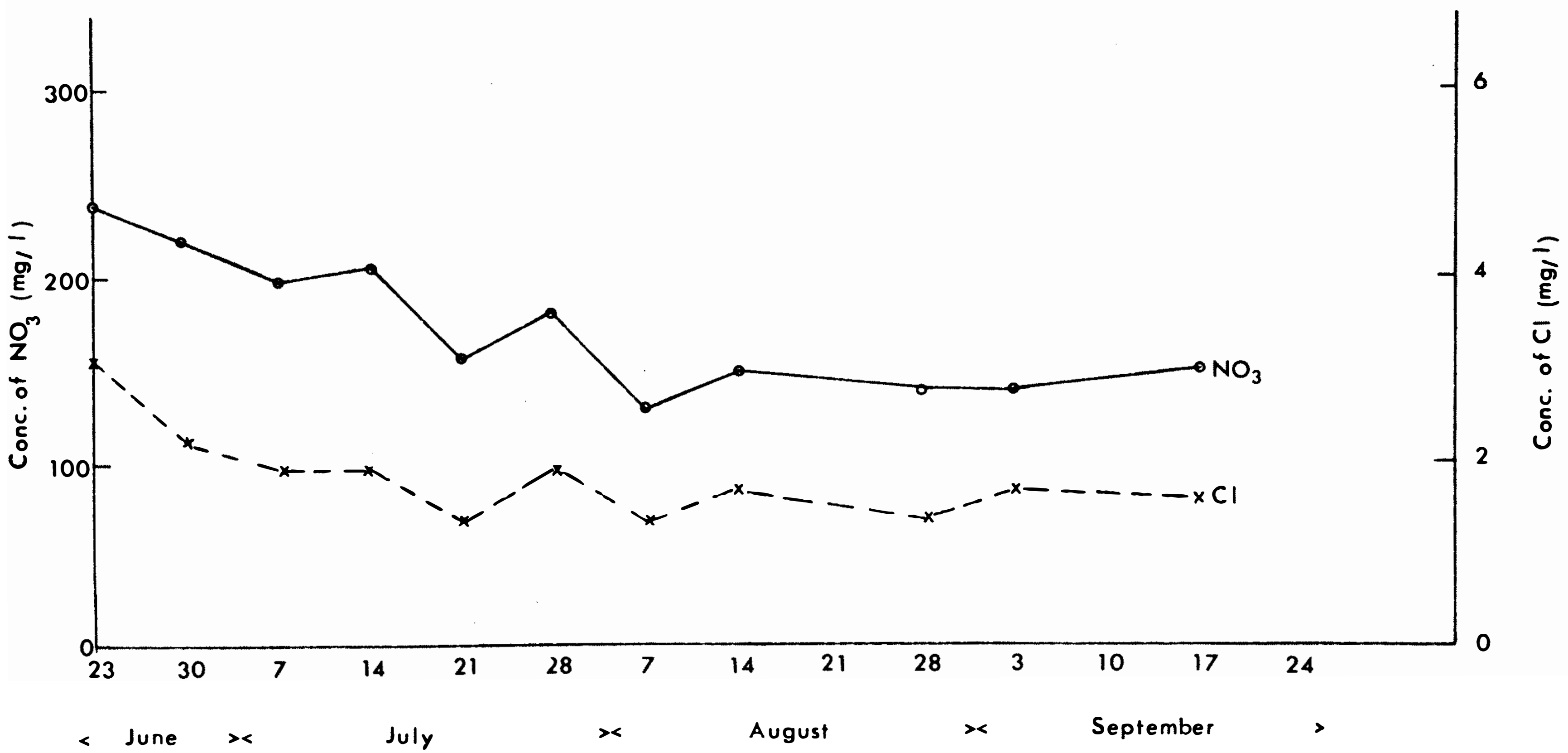

Figure 7. Concentration of NO_3 and Cl in Field C-14 at 60 cm during 1975 (r = 0.82)

Table 5. Total amount of nutrients collected annually (June 15-September 30) by soil water samplers at depths of 30 and 60 cm

Field	Year	Depth cm	Nutrient content per sampler (mg) NO_3	P	K	Ca	Mg
12	1972	30	52	13	4	-	-
		60	96	32	10	-	-
	1973	30	20	<1	17	39	7
		60	13	<1	10	50	30
	1974	30	27	1	14	99	29
		60	61	1	8	82	21
	1975	30	47	<1	6	66	16
		60	90	<1	8	60	20
40	1972	30	23	39	2	-	-
		60	85	50	9	-	-
	1973	30	87	<1	3	327	52
		60	95	1	5	97	20
	1974	30	64	1	4	121	26
		60	69	1	4	114	22
	1975	30	194	<1	3	111	24
		60	191	<1	4	74	20
C-14	1972	30	28	14	2	-	-
		60	175	50	14	-	-
	1973	30	151	<1	3	362	490
		60	90	<1	3	319	387
	1974	30	406	1	3	975	376
		60	511	1	3	867	547
	1975	30	665	<1	3	741	335
		60	344	<1	3	641	301

DISCUSSION

MOVEMENT OF NUTRIENTS

The predominance of Ca in the percolate water collected from various fields may be due primarily to mass action. Although the absolute amounts differed with individual fields, Ca was the major cation on the soils exchange complex (Table 1). Furthermore, free carbonate was present throughout the upper 60 cm of soil in Field C-14, and this would be another source of soluble Ca and Mg. Of the exchangeable cations, Ca and Mg predominate in most soils and because of this, they are displaced in greatest quantities by percolating water. In other lysimeter studies (Volk and Bell 1947, Kardos 1948, Stauffer and Rust 1954, Cole and Gessel 1963, Rains and Bledsoe 1976), Ca was the predominant cation in leachate whether under agricultural or forest conditions. Magnesium was generally present in the second largest concentration and directly reflected the ranking of exchangeable cations in the soil. Potassium and Na (in that order) were usually next in rank. Although Na was more easily displaced from soil colloids than K, the percentage of exchangeable Na in the soil was usually much lower. Chaiwanakupt and Robertson (1976) found that leaching of Ca, Mg, and K was related to cation exchange capacity and the extractable level of each constituent prior to leaching. Comparatively little K was removed in leachate in this study regardless of level of application of K fertilizers or available soil K. Although K salts are readily soluble, the K ion on application may be fixed in a relatively unavailable form through inclusion in the lattice of certain clay minerals; wetting and drying aid the process (Lyon *et al.* 1952). Thus, changes in the K content of percolate are due not only to leaching but also to fixation, exchange reactions, and K release from less available to more available forms. Leaching of K is lower in neutral and alkaline soils than in acid ones (Krause 1965), and this would help to explain the generally low amounts of K leached from the soils used in this study.

Nitrate is soluble and very mobile in well-drained soils (Lyon *et al.* 1952). The high contents of NO_3 and P in leachate collected at a depth of 60 cm during the year of seeding or transplanting suggested that both nutrients were subject to movement whenever a young crop was heavily fertilized and irrigated. Until its root system was fully developed the plant was unable to absorb large amounts of nutrients. Phosphorus concentration was high at 30 and 60 cm, indicating a slower rate of uptake. High concentration of NO_3 in leachate after crop removal may indicate either (1) dissolution of excess fertilizer NO_3 (or NO_3 formed from nitrification of residual NH_4-N), or (2) concentration of nutrients near the soil surface through evaporation of percolate. However, leachate content of other nutrients did not change significantly at either depth under fallow conditions, suggesting that movement of residual fertilizer N was the more likely cause of high NO_3 in the soil solution. Substantial amounts of NH_4-N compared to NO_3-N were applied as fertilizer (Table 4), but monitoring of nitrification was beyond the scope of the study.

It has been shown (Jones *et al.* 1974, Olsen *et al.* 1970, Richards and Wadleigh 1952, Schertz and Miller 1972, and Volz *et al.* 1976) that more NO_3 was leached from fallowed land than during cropping and that depth of migration of NO_3 could be altered depending on crop type. Cole and Gessel (1963) also found that more N was leached from a forest soil following logging. In the single instance where more NO_3 was leached under cropping than fallowing (Boswell and Anderson 1970), percolation along root channels was suggested.

The immobility of P in soil through fixation (formation of a less soluble P compound) is well documented (Lehr *et al.* 1959, Kardos 1964, Lyon *et al.* 1952, and Russel 1961). This phenomenon would account for the extremely small quantities of P found in leachate. In neutral and alkaline soils, P concentration in soil solution was reduced through precipitation as the relatively insoluble compound calcium phosphate, through adsorption by clay, and by calcium carbonate (Lindsay and Stephenson 1959, Weir and Soper 1962). Soils in the present study had little clay (< 10%), but calcium carbonate was found throughout Field C-14. Chaiwanakupt and Robertson (1976) found that although P leached from a soil column varied directly with the amount applied, P loss was drastically reduced by liming. Because of the low mobility of P in soil, the effectiveness of P fertilizers is dependent on proper placement.

Of the three major plant nutrients, nitrogen as nitrate migrated in greatest amounts from the root zone; movement of P and K in these soils was minimal. Irrigation is a necessary feature of most tree nurseries, but leaching losses are affected by the frequency and intensity of irrigation. Logan and McLean (1973) found that the amount of P removed by leaching was four times greater with constant irrigation rather than intermittent application. Singh and Sekhon (1976a) also reported minimal NO_3 loss with frequent light applications of water. In another paper, Singh and Sekhon (1976b) emphasized the importance of balanced fertilization. They found that less NO_3 was lost by leaching when P and K were also applied; still less NO_3 was leached when split applications were made. Therefore, although leaching losses of nutrients in tree nurseries may not always be avoidable, it should be possible to reduce them.

NITRATE-CHLORIDE RELATIONSHIP

Correlation between NO_3 and Cl in the soil solution during the second year of fallow rather than the first indicated that NO_3 movement in fallow soil may be due not only to residual soil NO_3 present when the crop is lifted but also to NO_3 newly formed through nitrification of previously applied NH_4-N. Since the formation of NO_3 from NH_4-N in soil is highly temperature-dependent (Sabey *et al.* 1959), there would likely be greater nitrification in the drier and warmer season, 1975.

Also, a poor NO_3-Cl relationship in Field C-14 during the wetter year (1974) may indicate that denitrification was also responsible for NO_3 losses.

It is recognized that both leaching and denitrification could play a role in NO_3 removal from the soil. Volk and Bell (1947) found that as much as 200% of the applied NO_3 was sometimes found in leachate compared to 100% for Cl, implying that nitrification was involved in NO_3

loss. However, Yimprasert *et al.* (1976) reported a similarity in the basic pattern of movement of NO_3 and Cl and concluded that leaching rather than denitrification was the primary mechanism through which NO_3 was lost. Heavier dosages (92 kg NO_3/ha and 405 kg Cl/ha) compared to those in this study (Table 4) and a shorter experiment (21 days) may have contributed to their findings (Yimprasert *op. cit.*) because biological activity would be relatively low.

CONCLUSIONS

1. In the seedbeds, the order of nutrient movement was Ca > NO_3 > Mg >> K > P, and in the transplant area the order was Ca > Mg > NO_3 >> K > P. Losses of P and K by leaching were extremely low, and apart from the first crop year, were negligible. Losses of Ca and Mg were related to their previous levels in the soil.
2. Heavy N fertilization and an undeveloped root system during the first crop year contributed to the high NO_3 concentration in leachate. Following crop removal, NO_3 loss was again high, possibly because residual fertilizer N had been transformed to NO_3.
3. Low correlation between NO_3 and Cl in leachate during the first year of fallow and a high correlation in the second year also suggested nitrification of residual fertilizer N soon after crop removal. A low NO_3-Cl correlation during an unusually wet year (1974) suggested that NO_3 losses were also due to denitrification.

RECOMMENDATIONS

1. Apply nitrogen fertilizer during the growing season. Two to four small applications are better than a single dosage of the equivalent amount.
2. Do not apply nitrogen fertilizers, especially ammonium nitrate, during the fall. Ammonium phosphate (e.g. 11-48-0) may be applied, but N should be supplemented during the following season.
3. Do not overirrigate. Apply only enough water to wet the root zone. A series of light applications is better than a single large

irrigation. Use a soil moisture meter to indicate when the soil is sufficiently wet.

4. Maintain a balanced fertilizer program (adequate N, P, and K) to obtain optimum plant growth. For these soils, about 90 kg N/ha, 40 kg P/ha, and 200 kg K/ha appear to be sufficient for each growing season. Leaching losses of nutrients are reduced through plant uptake.

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