Evaluation of Nitrogen use Efficiency at Various Soil Depths as Measured by Canola and Wheat Growth

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Abstract

A growth chamber experiment was conducted in columns to determine the availability of soil nitrogen at various depths to canola and wheat plants. Seven treatments under wet and dry watering regimes were imposed: 0 -15 cm, 15 - 30 cm, 30 - 45 cm, and 45 - 60 cm layers enriched with 15 $\mu g \bullet g^{-1}$ (30 $kg \bullet ha^{-1}$) of N and 0 - 30 cm, 15 - 45 cm, and 30 - 60 cm layers enriched with 7.5 $\mu g \bullet g^{-1}$ (30 $kg \bullet ha^{-1}$) of N (both rates as NH_4NO_3). Non significant differences in plant, seed, and straw mass values were observed among treatments in the irrigated wheat and canola experiments. Also, no trend in soil NO_3 removal was established for the soil layers sampled at harvest for these experiments. Variability within the treatments and/or lack of nitrogen response may have masked slight yield differences imposed by the N treatments. This variability may have been imposed from differences in the amount of leachate from the columns in the irrigated experiments. The dryland wheat experiment showed significant plant and seed mass responses to N enrichment treatments. The dryland canola experiment showed significant seed yield increases to the N enrichment amendments. In both the dryland wheat and canola experiments, soil NO_3 levels were very low in the 0 - 30 cm soil layer. This was attributed to plant removal of N from the upper soil horizons. Less variability in plant, seed, and straw mass values was observed in the dryland experiments because no leachate was collected from the soil columns.

Introduction

Canola and wheat are major crops on the Canadian prairies which require large amounts of soil and fertilizer nitrogen. Producers consult soil testing laboratories annually to determine the proper forms and amounts of nitrogen fertilizer to apply to ensure economic returns. Current nitrogen fertilizer recommendations assume that: soil and fertilizer nitrogen affect crop yield identically and soil nitrogen affects yield consistently over the 0 - 60 cm depth sampled (Laverty et al., 1987; SSTL, 1989).

Improvements in fertilizer nitrogen recommendations could be made by considering a marginal rate of substitution (MRS) value of soil nitrogen for fertilizer nitrogen for a particular crop under field conditions. MRS values are given by the following equation (Haby et al., 1983; Onken et al., 1985; Carefoot et al., 1989):

$$MRS = \frac{\partial Y/\partial SN}{\partial Y/\partial FN}$$

where: $\partial Y/\partial SN$ = slope of yield response curve to soil nitrate
and $\partial Y/\partial FN$ = slope of yield response curve to fertilizer nitrogen.

Carefoot et al. (1989) observed large differences in the MRS of soil nitrate for fertilizer nitrogen for wheat yield. The variability, in part, was attributed to differences in soil NO_3 availability at various soil depths. They concluded from the MRS values that soil NO_3 at depth (30 - 120 cm) is less available to wheat than surface soil NO_3 (0 - 30 cm). In a similar study, Onken et al. (1985) concluded that residual soil NO_3-N measured from 0 to 15 cm was a sufficient estimate of soil nitrogen for irrigated corn nitrogen fertilizer requirements. MRS values of soil for fertilizer nitrogen were observed to decrease with increasing depth of soil NO_3 measurement. This suggests that soil nitrogen at depth is less available for plant uptake than surface (0 - 15 cm) soil nitrogen.

Brown and Stark (1989) conducted long term field experiments with spring wheat involving nitrogen use efficiency and concluded that inorganic soil NO_3 and NH_4 in the 0 - 30 cm soil layer had significantly higher yield potential than that of the 30 - 60 cm soil layer. Haby et al. (1983) produced results from a winter wheat field study which indicate that soil NO_3-N in the 0 - 120 cm soil layer is approximately one-third as efficient as fertilizer nitrogen in terms of grain production. They hypothesize that plants remove soil nitrogen more efficiently form the upper profile than from the lower profile.

A growth chamber experiment was established in columns to determine the availability of soil nitrogen at various depths to canola and wheat uptake. An N enrichment technique was used to provide a tracer to determine from which soil depth canola and wheat obtained the most nitrogen and the relative efficiency of N uptake from N placed at depths below 30 cm.

Materials and Methods

A growth chamber experiment was established to determine soil nitrogen use efficiency at various soil depths in 10 x 60 cm PVC columns. Canola (*Brassica napus* 'Legend') and spring wheat (*Triticum aestivum* 'Katepwa') were grown in an Asquith soil (Orthic dark brown Chernozem) (Table 1) amended with seven N treatments to serve this purpose. Soil was collected from the Ah horizon (0 - 15 cm) of the Asquith soil and was dried, ground, and sieved to pass a 6 mm screen before use in the columns.

Table 1. Basic properties of the Asquith soil used in the study.

Depth (cm)	Texture	pH	Conductivity ($mS \cdot cm^{-1}$)	Nutrient levels ($\mu g \cdot g^{-1}$) NO_3-N	P	K	SO_4-S
0 - 15	loamy sand	6.7	0.2	10.0	38	310	8.2
15 - 30	loamy sand	7.2	0.2	4.5	-	-	6.5
30 - 60	loamy sand	7.4	0.3	4.0	-	-	9.5

Four replicates were used in experimentation and two watering regimes were considered: 'irrigated'; 71.21 cm H_2O (98 days) and 'dryland'; 48.96 cm H_2O (97 days). The irrigated columns received 170 ml additions of distilled deionized (dd) H_2O twice weekly and the dryland columns received 170 ml dd water weekly. Additional dd H_2O as the plants required in a 2:1 irrigated:dryland ratio.

The treatments were established so that each column contained a total of 308 mg of soil nitrogen split into four horizons: 0 - 15 cm, 15 - 30 cm, 30 - 45 cm , and 45 - 60 cm. Aliquots of 20.0 and 25.0 ml of 1500 and 2400 $\mu g \cdot ml^{-1}$ NH_4NO_3 solutions (35 % N) were added to 2.800 and 1.400 kg of soil to create 7.5 and 15 $\mu g \cdot g^{-1}$ N enriched soil layers. Each column contained a total of 5.600 kg of treated and untreated soil. The N enriched layer of soil was placed in one or two of the horizons in a column. The remaining layers contained 10.0 $\mu g \cdot g^{-1}$ of NO_3-N. Seven N treatments were considered: 0 - 15 cm, 15 - 30 cm, 30 - 45, and 45 - 60 cm layers enriched with 15 $\mu g \cdot g^{-1}$ (~ 30 $kg \cdot ha^{-1}$) of N and 0 - 30 cm, 15 - 45 cm, and 30 - 60 cm layers enriched with 7.5 $\mu g \cdot g^{-1}$ of N.

An application of 20 $\mu g \cdot g^{-1}$ of phosphorus as KH_2PO_4 was added to each column to ensure adequate phosphorus levels. Eight canola and wheat seeds per column were seeded at 3 and 4 cm depths into moist soil. The canola and wheat seedlings were thinned to 2 and 4 plants per column respectively two weeks after seeding. A 16-h photoperiod was used at diurnal temperatures of 21 ± 1 °C and 16 ± 1°C respectively. The growth chamber light intensity was 175 ± 10 $\mu E \cdot s^{-1} \cdot m^{-2}$ at the soil surface for the duration of the experiment. A constant suction of ~ 34 kPa (1/3 atm) was maintained at the bottom of each column for the entire growth period by fastening a tensiometer cup and suction apparatus to the bottom of each column according to Karamanos and Rennie (1981[ab])(Figure 1).

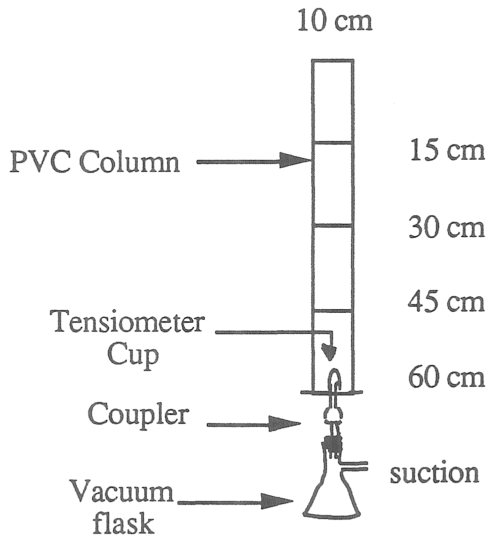

Figure 1. Schematic diagram of a column used in experimentation.

During the course of the experiment, the canola and wheat plants were monitored weekly for height, vigor, and leachate volume differences until the plants reached senescence. The plants were harvested by cutting at 2 cm above the soil surface 13 weeks after seeding and dried at 60 °C for 1 week. The total plant mass was determined for each column. The plant samples were then thrashed and the seed and straw masses were measured. Sub-samples of the seed and straw were saved for future analysis of ^{15}N uptake differences. After harvest, each column was cut into four 15 cm segments and the soil from each depth was sampled. Each soil sample from each 15 cm layer of soil was dried, ground and analyzed for $CaCl_2$-extractable NO_3-N levels.

All statistical mass values were generated from analysis of variance with a protected least significant difference at 95 % significance according to Steel and Torrie (1980).

Results and Discussion

No significant differences in plant, seed, or straw mass values were observed among the N enrichment treatments for the irrigated wheat experiment (Table 2). Some other factor was likely influencing the yield component of this experiment therefore soil NO_3 levels had little effect on plant vigor.

Table 2. Average plant, seed, and straw masses (g) of 'irrigated' wheat.*

Treatment	Plant mass (g)	Seed mass (g)	Straw mass (g)
0 - 15 cm 15 $\mu g \cdot g^{-1}$ N	7.409a	3.226a	4.183a
15 - 30 cm 15 $\mu g \cdot g^{-1}$ N	8.853a	3.771a	5.083a
30 - 45 cm 15 $\mu g \cdot g^{-1}$ N	8.442a	3.614a	4.869a
45 - 60 cm 15 $\mu g \cdot g^{-1}$ N	8.242a	3.400a	4.842a
0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N	7.139a	2.922a	4.259a
15 - 45 cm 7.5 $\mu g \cdot g^{-1}$ N	6.988a	2.978a	4.093a
30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N	7.735a	3.545a	4.231a

* Values with different letters represent significant differences (95 %).

Soil NO_3 levels for the irrigated wheat experiment (Table 3) show three possible observations for this experiment. No definite trend exists between nitrogen placement and soil NO_3-N levels. For example, the 15 - 30 cm 15 $\mu g \cdot g^{-1}$ N treatment showed no significant enrichment in the 15 - 30 cm depth relative to the other treatments. The surface soil (0 - 15 cm) of all seven treatments shows low NO_3-N levels and soil at the 30 - 60 cm depth shows slight NO_3 enrichment. This suggests that nitrogen may have been removed from upper soil horizons. The NO_3 removal could have been in the form of plant uptake or leaching to lower depths in the columns. The irrigated wheat columns had significant amounts of leachate in variable as as result of the extra water applied. This may have moved soluble NO_3 to lower depths in the columns or completely removed large amounts of NO_3 from the columns. The variability in leachate volumes may have induced variable yield responses in this experiment.

Table 3. Average soil NO_3-N values of 'irrigated' wheat columns ($\mu g \cdot g^{-1}$).*

Treatment	0-15 cm	15-30 cm	30-45cm	45-60 cm
0 - 15 cm 15 $\mu g \cdot g^{-1}$ N	3.425a	6.850a	7.575abc	7.800b
15 - 30 cm 15 $\mu g \cdot g^{-1}$ N	1.725b	3.900b	5.125c	6.075b
30 - 45 cm 15 $\mu g \cdot g^{-1}$ N	1.717b	6.895a	11.448a	18.192a
45 - 60 cm 15 $\mu g \cdot g^{-1}$ N	1.750ab	5.275ab	9.225ab	11.150ab
0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N	2.417ab	5.645ab	9.123ab	10.492ab
15 - 45 cm 7.5 $\mu g \cdot g^{-1}$ N	1.834ab	5.090ab	7.196bc	8.959b
30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N	1.542b	4.770b	5.448bc	14.467ab

* Values with different letters represent significant differences (95 %).

The plant and straw masses of the irrigated canola experiment (Table 4) show no significant differences among N enrichment treatments. A slight increase in seed mass for the 15 - 30 cm 15 $\mu g \cdot g^{-1}$ N treatment may have been a result of increased nitrogen availability relative to the 45 - 60 cm 15 $\mu g \cdot g^{-1}$ N treatment but lack of a definite trend for the treatments tarnishes this observation. Overall, the nitrogen treatments had no significant effect on the growth and development of canola in this experiment. The lack of N effect may have been due to variability in column leachate volume which induced variable yield responses.

Table 4. Average plant, seed, and straw masses (g) of 'irrigated' canola.*

Treatment	Plant mass (g)	Seed mass (g)	Straw mass (g)
0 - 15 cm 15 $\mu g \cdot g^{-1}$ N	6.003a	1.848ab	4.156a
15 - 30 cm 15 $\mu g \cdot g^{-1}$ N	6.167a	2.108a	4.060a
30 - 45 cm 15 $\mu g \cdot g^{-1}$ N	5.944a	1.798ab	4.146a
45 - 60 cm 15 $\mu g \cdot g^{-1}$ N	5.285a	1.633b	4.192a
0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N	5.935a	1.803ab	4.133a
15 - 45 cm 7.5 $\mu g \cdot g^{-1}$ N	6.302a	1.911ab	4.392a
30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N	6.728a	1.843ab	4.886a

* Values with different letters represent significant differences (95 %).

Extractable NO_3-N levels for the irrigated canola experiment in the 0 - 30 cm layer show no significant differences among treatments and are all at very low levels (Table 5). This suggests that the majority of the plant uptake of nitrogen came from this layer for all treatments. Unlike the NO_3-N levels of the irrigated wheat experiment (Table 3), NO_3-N levels at depth (30 - 60 cm) for this experiment are low (Table 4). This indicates that the soluble NO_3 at depth was removed by plant uptake or more likely removed through leaching.

Table 5. Average soil NO_3-N values of 'irrigated' canola columns ($\mu g \cdot g^{-1}$).*

Treatment	0-15 cm	15-30 cm	30-45cm	45-60 cm
0 - 15 cm 15 $\mu g \cdot g^{-1}$ N	1.677a	3.308a	3.878a	3.194ab
15 - 30 cm 15 $\mu g \cdot g^{-1}$ N	1.727a	3.583a	4.603a	3.394a
30 - 45 cm 15 $\mu g \cdot g^{-1}$ N	2.127a	2.908a	3.428ab	2.969ab
45 - 60 cm 15 $\mu g \cdot g^{-1}$ N	2.075a	2.450a	1.950b	1.600b
0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N	1.550a	3.000a	4.125a	3.550a
15 - 45 cm 7.5 $\mu g \cdot g^{-1}$ N	1.575a	2.775a	3.525a	3.400a
30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N	1.702a	2.683a	3.203ab	2.894ab

* Values with different letters represent significant differences (95 %).

The dryland wheat experiment only showed significant differences among treatments for total plant and seed mass values. No significant differences were observed between straw mass values (Table 6). The 0 -15 cm 15 $\mu g \cdot g^{-1}$ N and 0 - 30 cm and 30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N treatments showed significantly higher plant mass values than the 30 - 45 cm 15 $\mu g \cdot g^{-1}$ N treatment and slightly higher values than the remaining treatments. Higher seed mass values occur in the 0 - 15cm and 15 - 30 cm 15 $\mu g \cdot g^{-1}$ N and 0 - 30 cm 30 - 60 cm and 7.5 $\mu g \cdot g^{-1}$ N treatment relative to the 30 - 45 cm 15 $\mu g \cdot g^{-1}$ N treatment. These results suggest that surface placed nitrogen may have caused a yield response for the dryland wheat experiment. However, the yield response for the 30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N treatment contradicts this observation.

Table 6. Average plant, seed, and straw masses (g) of 'dryland' wheat.*

Treatment	Plant mass (g)	Seed mass (g)	Straw mass (g)
0 - 15 cm 15 $\mu g \cdot g^{-1}$ N	6.880a	3.031a	3.850a
15 - 30 cm 15 $\mu g \cdot g^{-1}$ N	6.361ab	2.995a	3.366a
30 - 45 cm 15 $\mu g \cdot g^{-1}$ N	5.818b	2.391b	3.437a
45 - 60 cm 15 $\mu g \cdot g^{-1}$ N	6.487ab	2.825ab	3.662a
0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N	6.892a	3.037a	3.855a
15 - 45 cm 7.5 $\mu g \cdot g^{-1}$ N	6.239ab	2.572ab	3.667a
30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N	6.889a	3.022a	3.864a

* Values with different letters represent significant differences (95 %).

As with the irrigated wheat experiment, the surface (0 - 30 cm) layer of soil for the dryland wheat experiment showed very low levels of soil NO_3-N (Table 7). This suggests that the majority of plant uptake of nitrogen from the soil in the columns occurred from the upper 30 cm. The 30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N treatment showed significantly more soil N than the other treatments for both the 0 - 15 cm and 15 - 30 cm soil depths (Table 7). This indicates that a larger amount of nitrogen was available to the plant at the soil surface and may explain the high yield that surface treatments produced in terms of plant and seed mass values.

More soil NO_3-N was present in the 30 - 45 cm and 45 - 60 cm soil layers relative to the surface soil layers (0 - 15 cm and 15 - 30 cm) in the dryland wheat experiment (Table 7). This is in agreement with the irrigated wheat experiment (Table 3). Two explanations are possible, soil NO_3 from upper layers leached to depth or less plant uptake of nitrogen occurred from the 45 - 60 cm soil depth. Either explanation is valid. For example, the 30 - 45 cm 15 $\mu g \cdot g^{-1}$ N treatment has a NO_3 level of 8.595 $\mu g \cdot g^{-1}$ which indicates plant uptake and the 0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N treatment has a NO_3 level of 29.750 $\mu g \cdot g^{-1}$ which indicates an accumulation of NO_3 from upper horizons. No leachate was collected from these columns so NO_3 was lost from the columns in the form of leaching during this experiment.

Table 7. Average soil NO_3-N values of 'dryland' wheat columns ($\mu g \cdot g^{-1}$).*

Treatment	0-15 cm	15-30 cm	30-45cm	45-60 cm
0 - 15 cm 15 $\mu g \cdot g^{-1}$ N	1.525b	3.125b	4.475b	10.225bc
15 - 30 cm 15 $\mu g \cdot g^{-1}$ N	1.050b	2.975b	6.125ab	14.700bc
30 - 45 cm 15 $\mu g \cdot g^{-1}$ N	1.844b	5.479ab	6.780ab	8.595c
45 - 60 cm 15 $\mu g \cdot g^{-1}$ N	1.975b	3.350ab	4.425b	24.050ab
0 - 30 cm 7.5 $\mu g \cdot g^{-1}$ N	1.950b	3.475ab	7.975ab	29.750a
15 - 45 cm 7.5 $\mu g \cdot g^{-1}$ N	1.625b	3.750ab	10.725a	12.950bc
30 - 60 cm 7.5 $\mu g \cdot g^{-1}$ N	4.100a	5.850a	7.900ab	13.725bc

* Values with different letters represent significant differences (95 %).

The dryland canola experiment showed no significant differences in plant and straw masses among N enrichment treatments. Significant yield differences were observed among treatments for the seed mass measurements (Table 8). The 0 - 15 cm and 15 - 30 cm 15 $\mu g \bullet g^{-1}$ N and 0 - 30 cm 7.5 $\mu g \bullet g^{-1}$ N treatments appeared to produce the highest seed yields (1.684 g, 1.450 g, and 1.437 g respectively) relative to the other treatments (Table 8). This indicates a positive yield response to soil nitrogen present in surface horizons.

Table 8. Average plant, seed, and straw masses (g) of 'dryland' canola.*

Treatment	Plant mass (g)	Seed mass (g)	Straw mass (g)
0 - 15 cm 15 $\mu g \bullet g^{-1}$ N	5.906a	1.684a	4.216a
15 - 30 cm 15 $\mu g \bullet g^{-1}$ N	5.846a	1.450ab	4.390a
30 - 45 cm 15 $\mu g \bullet g^{-1}$ N	5.728a	1.033c	4.689a
45 - 60 cm 15 $\mu g \bullet g^{-1}$ N	5.462a	1.215bc	4.246a
0 - 30 cm 7.5 $\mu g \bullet g^{-1}$ N	6.025a	1.437ab	4.581a
15 - 45 cm 7.5 $\mu g \bullet g^{-1}$ N	5.642a	1.096c	4.540a
30 - 60 cm 7.5 $\mu g \bullet g^{-1}$ N	5.850a	1.289bc	4.561a

* Values with different letters represent significant differences (95 %).

The soil NO_3-N levels for the dryland canola experiment (Table 9) are very low and consistent among treatments. The low levels of soil NO_3-N are similar to the levels observed in the irrigated canola experiment (Table 5). No significant differences in soil NO_3-N levels were observed among treatments for the 0 - 15cm, 15 - 30 cm, and 30 - 45 cm soil depths. No accumulation of soil NO_3-N in the 45 - 60 cm soil layer was observed. This is significant, because no leachate was collected from the columns during this experiment. This means that plant removal of soil NO_3 likely occurred over all four depths with the majority occurring in the upper 30 cm of soil.

Table 9. Average soil NO_3-N values of 'dryland' canola columns ($\mu g \bullet g^{-1}$).*

Treatment	0-15 cm	15-30 cm	30-45cm	45-60 cm
0 - 15 cm 15 $\mu g \bullet g^{-1}$ N	0.646a	1.378a	1.558a	1.801b
15 - 30 cm 15 $\mu g \bullet g^{-1}$ N	0.721a	1.478a	1.658a	2.126b
30 - 45 cm 15 $\mu g \bullet g^{-1}$ N	1.046a	1.528a	1.758a	4.601a
45 - 60 cm 15 $\mu g \bullet g^{-1}$ N	0.950a	1.450a	1.475a	1.900b
0 - 30 cm 7.5 $\mu g \bullet g^{-1}$ N	0.921a	1.603a	1.833a	1.626b
15 - 45 cm 7.5 $\mu g \bullet g^{-1}$ N	0.871a	1.428a	1.408a	1.576b
30 - 60 cm 7.5 $\mu g \bullet g^{-1}$ N	0.825a	1.425a	1.575a	2.425ab

* Values with different letters represent significant differences (95 %).

The effects of the seven treatments for the irrigated wheat and canola experiments in terms of yields were likely masked by the variability associated with the column experiments. The height and vigor observations made during plant growth closely reflect the variable results within each treatment and suggest that the variability was a function of differences in vacuum among the columns. Such differences would induce changes in the nutrient status, water availability, and physical growing conditions from column to column. For example, the volume of leachate collected from the irrigated wheat and canola columns negatively correlate with the yields of the irrigated experiments (data not shown).

Another explanation as to why there were minimal yield differences among treatments for these experiments could be that Liebig's law of minimum may have not been followed. The soil may not have been deficient enough in nitrogen to induce yield differences as a function of applied nitrogen. Perhaps a higher rate of NH_4NO_3 should have been applied as a treatment to induce differences in plant mass.

Analysis of the straw and seed for total N and N uptake is essential to determine if the treatments had an effect on the canola and wheat growth under the experimental conditions imposed.

Summary and Conclusions

No definite pattern of nitrogen uptake as measured by plant, straw, and seed mass was established for the irrigated wheat and canola experiments. Analysis of soil NO_3 levels in the irrigated experiments showed no definite trend of plant N removal from the soil. Any slight results produced by the various nitrogen enrichment treatments were likely masked by the variability associated with the experiments. The dryland wheat and canola experiments showed positive yield responses to surface placed N and large plant removal of N from the upper soil horizons in all treatments. Analysis of N and total nitrogen uptake in the seed and straw of the canola and wheat plants is essential to see if the imposed treatments affected the test plants.

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