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Accumulation and Loss of Nitrogen During Growth and Maturation of Cereal Rye *(Secale cereale)*[1]

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ABSTRACT

The loss of total N from herbage of cereal rye after anthesis was studied by recovering herbage, roots, and anthers of rye grown in soil (under dryland conditions), nutrient solution, and sand culture. The amount of N in herbage of dryland rye decreased an average of 7.9 kg/ha during the 2 weeks following anthesis. Potential loss of N from herbage through shedding of anthers and pollen was estimated at 16 kg/ha. Rye grown in sand or solution culture continued to absorb and accumulate N after anthesis which masked the N lost during anthesis. We found no evidence which would suggest a transport of N from herbage to roots under either dryland conditions, or sand or nutrient culture.

Additional index words: **Nitrogen accumulation, Flowering, Nitrogen loss.**

THE total N concentration of grasses declines continuously during growth and maturation. However, when N is expressed on the basis of herbage dry matter it tends to obscure changes in the absolute amount of N because of concurrent changes in dry matter. Reports of a decline in the absolute amount of N in all or portions of herbaceous plants are less common. Doneen (2) observed a decline in the amount of total N contained in the above ground portion of wheat in a dry year, when moisture was inadequate for production of grain. He assumed that N was translocated to roots. Tanaka (6) observed the loss of N from rice leaves by leaching in rain or dew. Cepikova (1) and Weinmann (7,8,9) concluded that an autumnal translocation of N from shoots to roots of perennial grasses accounted for a decrease in amount of N contained in shoots.

Sneva, Hyder, and Cooper (4) and Sneva and Hyder (5) reported the loss of N from above ground portions of crested wheatgrass and cereal rye grown for hay under dryland conditions. The loss of N from herbage of cereal rye was greatest 1 week after anthesis, but the decline was more or less continuous between early flower and hard dough. The amount of total N in herbage of rye declined by 45% (20.8 kg N/ha) when cropped biennially, and 43% (7.8 kg N/ha) when cropped annually during a 3-week period after anthesis.

This paper presents the results of experiments with cereal rye grown under dryland conditions, in sand cultures, and in nutrient solutions. We conducted these experiments to determine if the total N lost from the herbage of dryland rye could be accounted for by the loss of N through the shedding of floral organs, by translocation from shoots to roots, or both.

METHODS AND MATERIALS

Dryland rye experiments. To recover roots of dryland rye we formed polyethylene film into cylinders 25.4 cm in diameter by 76 cm deep (approximately 38 liters) and sewed them together on the sides and bottom. Fourteen such cylinders were placed into holes in the soil and each was filled with 41 kg of screened sandy loam soil. Rye was seeded in the fall and thinned to three plants per cylinder in the spring. One cylinder contained a plant which did not flower so another cylinder was intentionally discarded. Six cultures were removed on July 7 and the remaining six on June 24. Shoots were severed at the soil surface and roots recovered by washing. All samples were dried at 70 C, weighed, and ground in a Wiley mill.

A field of rye was sampled immediately prior to anthesis, and 1- and 2- weeks later by hand clipping 20 plots selected at random. Each plot was 0.84 m².

Twenty-three heads were selected on the first harvest date from which we removed the stamens. The number of heads per square meter were estimated by counting heads within a 0.093 m² frame from 36 randomly selected plots.

Estimation of total N lost during anthesis. Heads were collected prior to bloom of the oldest florets, and the stamens removed from all florets. All stamens frm the same head were placed in a vial, dried in a dessicator over $CaSO_4$, weighed, and analyzed for total N by micro-Kjeldahl. Stamens were collected from fields of dryland rye and from rye grown in sand culture.

Sand cultures. One plant of cereal rye was grown in 6 kg of #16 sand contained in each of 54 plastic pots. Cultures were watered daily, except on weekends, and irrigated with 100 ml of nutrient solution (described in the following section) on Monday, Wednesday, and Friday. Cultures were flushed each Monday with excess water prior to adding the nutrient solution. No attempt was made to account for the total N added or flushed away.

Three cultures were harvested on Monday and Thursday of each week beginning June 3 (early jointing). All six plants were analyzed individually and averaged to obtain the weekly mean. Sand was washed from roots and dry weights of shoots, roots, and heads obtained. Harvesting continued for 9 consecutive weeks, at which time mature seeds were present and most of the older leaves were dead.

Nutrient solution cultures. Rye was germinated in sand and transferred to cultures containing a complete nutrient solution on June 12. Plants were in the 3- to 4-leaf stage of growth. Each culture contained four rye plants in an initial volume of 7 liters of solution of the following concentration, mmoles/liter: KH_2PO_4 2.0, $MgSO_4$ 2.0, $Ca(NO_3)_2$ 3.7, $(NH_4)_2SO_4$ 1.78. Micro-

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nutrients were added in ppm as follows: Fe-EDTA 5.0, Mn 0.36, Zn 0.081, B 0.087, Cu 0.025, Mo 0.041. The solution provided 150 mg/liter of total N. The initial pH was 5.5 and was maintained below pH 7.0 by regular addition of new solution.

Seven cultures were harvested June 27 (late jointing stage), July 8 (early anthesis), and July 31 (mature seed). Each culture had received 7.0, 10.0, and 16.0 liters of solution, respectively, during the course of the experiment. Tops were severed from roots at the crown. Tops and roots were dried at 70 C, weighed, ground in a Wiley mill, and stored in glass jars for analysis.

Analytical methods. Total N was determined by standard macro-Kjeldahl procedures using the salicyclic acid modification. The micro-Kjeldahl procedure was as follows: samples of 50 to 100 mg were weighed into Folin-Wu tubes, and 1 g of anhydrous sodium sulfate plus Se (100:1) and 2.5 ml of concentrated H_2SO_4 were added. The samples were digested in tubes placed through holes in a Transite sheet and resting on a thin sheet of asbestos covering a stove element. The acid fumes condensed on the sides of the tube about two-thirds the distance from the bottom. Digestion was performed in a hood and carried out for 1 hour after clearing. The digested mixture was diluted to 35 ml. An aliquot was removed and analyzed for NH_4-N, according to Hill-Collingham and Wagner (3), except that the gum acacia and Nessler's reagent were mixed prior to use and added together.

Both procedures determine total nitrogen, and all references to N in this paper refer to total N.

RESULTS

Recovery of total N in dryland rye. Total N contained in both shoots and roots of rye grown in polyethylene cylinders decreased during the 17-day period after anthesis (Table 1). Part of the loss of N from roots after anthesis may have been due to the loss of root dry matter (Table 1), probably by decomposition.

The total N contained in the aboveground portion of dryland rye sampled prior to anthesis and 1 and 2 weeks later, was 28.8, 18.8, and 23.0 kg/ha, respectively. The yield of N prior to anthesis was significantly higher (1% level) than the yield 1 and 2 weeks later, but the difference in yield between 1 and 2 weeks after anthesis was not significant at the 5% level of probability. If we assume that total N yields 1 and 2 weeks after anthesis were samples from the same population, then the mean yield was 20.9 kg N/ha. Thus, there was an apparent decrease of 7.9 kg N/ha from the herbage of rye during the 2 weeks after anthesis.

Average stamen yield was 103 mg dry weight per head with a N concentration of 4.00%. The amount of N contained in stamens was 4.10 ± 0.36 (P = 5%) mg/head.

There were 393 ± 51 (P = 5%) rye heads per square meter. Thus, the potential loss of N Via loss of stamens was 16.1 kg N/ha, which was far in excess of the actual measured loss of 7.9 kg N/ha.

Recovery of N during growth and maturation of rye in sand culture. Stamen yield from rye grown in sand culture was 87.6 ± 8.16 (P = 5%) mg with a N concentration of 4.44%. The yield of total N in stamens was 4.03 ± 0.46 (P = 5%) mg/head.

Amount of total N contained in the shoots of rye increased during growth and maturation from 62 mg on June 5 to 335 mg/plant on July 31 (Fig. 1). Total N appeared to be redistributed within rye shoots. The data suggest that N was translocated from shoots to the developing inflorescence beginning about 10 days after anthesis. Total N contained in roots, however, did not change appreciably from 31.5 mg during the entire period of growth and maturation (Fig. 1).

Table 1. Changes in dry matter and total N in cereal rye during a 17-day period after anthesis when cultured under dryland conditions.

Dry matter and total nitrogen/cylinder	Stage of development and date		Level of significance*
	July 7	July 24	
			%
Shoot dry matter, g	35.0	36.0	ns
Root dry matter, g	16.0	13.0	93.3
N in shoots, %	1.83	1.12	99.9
N in roots, %	0.95	0.69	89.6
N in shoots, mg	630.0	410.0	99.7
N in roots, mg	150.0	90.0	99.6
N in whole plant, mg	780.0	500.0	99.9

* Probabilities computed following the procedure suggested by Swartzendruber. Soil Sci. Soc. of Am. Proc. 25:70-71. 1961.

Table 2. Nitrogen in mg/pot in cereal rye at three stages of development when grown in nutrient solution.

Plant part	Stage of development and date		
	Late boot, June 27	Anthesis, July 8	Mature, July 31
Shoots	326	637	822
Roots	65	149	244
Heads	---	138	549
Stamens*	---	18	300

* Estimated as the product of number of heads × 4.03 mg N per head.

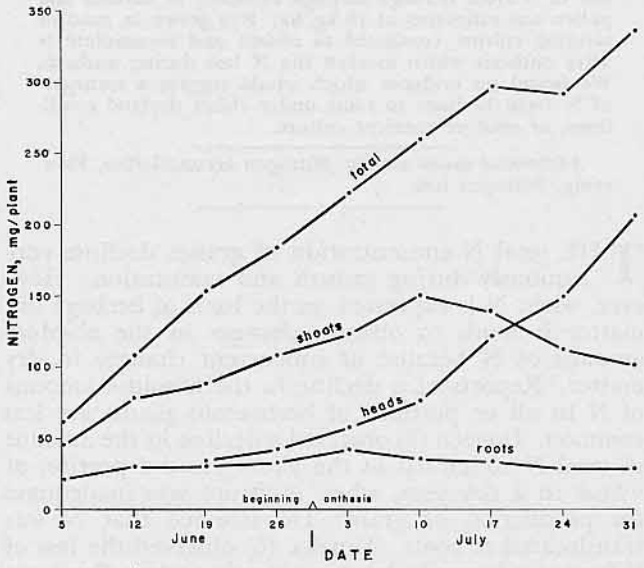

Fig. 1. Total nitrogen accumulated in cereal rye grown in sand culture.

Recovery of N in rye grown in solution culture. When rye was grown in solution culture, total N in shoots, heads, and roots increased from late boot to mature seed (Table 2). The amount of N lost in shedding of pollen and anthers was estimated at 300 mg (based on the number of heads × 4.03 mg N/head), but this loss was not apparent because of continued N absorption.

DISCUSSION

Total N contained in shoots of growing plants of cereal rye is in a transient state, and can change considerably over relatively short periods of time. The change in total N may be an accumulation, a redistribution, or an absolute loss. Nitrogen is continuously lost during flowering, first, through the shedding of pollen and then by shedding of anthers and filaments. The flowering process in a field of rye, and to a lesser extent in an individual head, extends over a period of 10 to 21 days.

The total N contained in herbage during and after anthesis is the net result of accumulation relative to loss. More total N was lost from the herbage of dryland rye during anthesis than was accumulated. The net result was a decline in the yield of total N.

When rye was grown in sand or solution culture, the total N contained in the herbage accumulated throughout the entire period. Although N was lost from the herbage during flowering, N uptake was large relative to N loss and the loss was completely masked.

We were unable to observe anything that would suggest a net translocation of N from shoots to roots as the plants matured. All increases in root total N were associated with increases in root dry matter.

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