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NITROGEN, THE CRITICAL ELEMENT AND ITS ASSESSMENT IN MINE RECLAMATION

by Michael J. Rowell

INTRODUCTION

The long term objectives of mine reclamation may differ from the initial requirements where site stability and soil erosion are generally key considerations. The overall goal is to create a stable self sustaining vegetative cover that is in harmony with surrounding undisturbed areas. Consequently, in terms of soil physical and chemical needs, the methods used to reach long and short term objectives may differ widely. However, despite this conflict, the assessment of soils and their subsequent treatment are not necessarily incompatible.

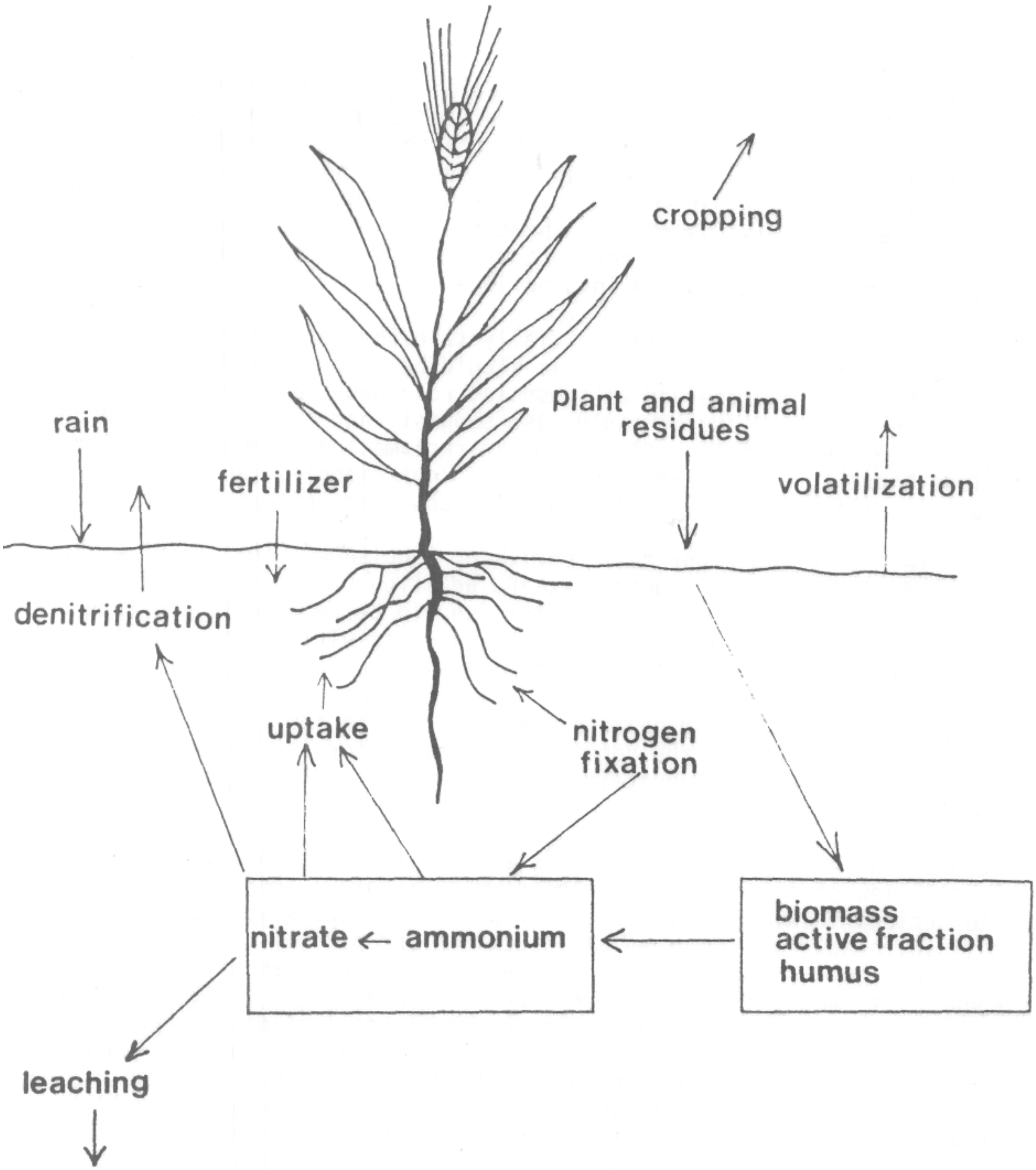
Typically soil assessment will initially take the form of an inventory of materials to indicate which soils should be used as surface amendments and which should be reserved as subsoils, road beds, backfill and so forth. This initial survey would also suggest what treatments would be required to make surface soils useful in reclamation. Treatments might include those to correct acidity, nutrient deficiencies, and to improve structure, moisture holding, drainage or reduce toxicities.

The correction of nutrient deficiencies or imbalances might require the mixing of different soil substrates and addition of mineral fertilizers. The extent and nature of the amendments should be related to the type of vegetation cover, its productivity level and its ultimate form within the landscape. The initial phase of mine-site reclamation often concerns soil stability and erosion control. This involves correct engineering of the subsoil as well as adequate preparation of the seedbed material to support rapid growth of the vegetation. The latter is frequently achieved by the application of moderately large amounts of mineral fertilizers over a period of several years.

Nitrogen is invariably the main nutrient limitation to plant growth. An overall view of the nitrogen cycle shown in Figure 1 shows that the interactions between the different components of the system are complex and involve numerous intermediate reactions and pathways. Many climatic variables, soil characteristics and management practices affect plant productivity and the demand for nitrogen. The nitrogen cycle is a biological equilibrium between a large organic pool of nitrogen and a small inorganic fraction. Gains and losses to the inorganic pool occur at several different points and each attains significance under a different set of soil conditions. Denitrification is favoured by high nitrate concentrations and warm water-saturated conditions. Atmospheric nitrogen fixation is high in legumes and certain other nodulated plants and can be more significant in vegetation under nitrogen stress. Also, volatilization of ammonia may be important in soils of low absorbing capacity at high pH. Soil exhibit different rates of conversion of

FIGURE 1

The Nitrogen Cycle in Soil



organic nitrogen to ammonium and of ammonium to nitrate. Accumulation of nitrate in humid climates may result in leaching of nitrate to depths below the root absorbing zone.

How can we predict the reactions of nitrogen in the soil and estimate the requirement for this important element? What sort of evaluation and testing procedures are available?

In the agricultural arena in Canada we might justifiably make a sweeping statement that, for annual crops in dry areas with a continental type of climate (e.g. Prairie Provinces), the measurement of residual mineral nitrogen in the soil in the fall or spring is a good indicator of the nitrogen supply during the next growing season. In more humid regions with a milder climate a direct prediction of nitrogen availability is more variable. However, with mine reclamation situations where perennial covers are involved, the situation is difficult regardless of climate.

Since we often get spectacular responses from the application of inorganic nitrogen fertilizers we tend to assume that the residual effects from such nitrogen applications will be significant in terms of long term reclamation of mine sites. However, studies which we have carried out in Alberta involving land that has been reclaimed for up to 15 years suggest that even large applications of nitrogen over the initial years of revegetation do not increase long term productivity. A summary of some experimental studies is shown in Table 1.

It would appear that the amount of stable humus-bound nitrogen present initially in the soil mix is far more important than nitrogen applied as inorganic fertilizer. In fact a low nitrogen regime can be used to stimulate growth and persistence of nitrogen fixing species and result ultimately in higher productivity once inorganic fertilization is eliminated.

A recent survey by Keeney (1982) indicated that a wide variety of types of test have been carried out to estimate nitrogen availability in soils (see Table 2). Soil testing laboratories generally base nitrogen recommendations on a combination of laboratory tests and yield potential and management information.

A good test procedure should be able to directly or indirectly predict the potential of the soil to produce plant available nitrogen. The test should also be rapid, inexpensive, reproducible and not seriously influenced by sample handling or pretreatment.

In arid regions, especially where growing periods are separated by a dormant winter period, the measurement of residual nitrate has proved to be an adequate soil test method. In more humid regions the rapid leaching and déni tri fi cation of soluble nitrogen has made testing more of a problem.

For soil reclamation purposes the approach initiated by Stanford in measuring the mineralization potential or "nitrogen supplying power" of

TABLE 1

A COMPARISON OF PLANT PRODUCTIVITY RELATED TO FERTILIZER INPUTS AND TIME IN THREE EXPERIMENTS ON TAILINGS POND DIKES AT FORT McMURRAY, ALBERTA

Soil Mix	Starting date	Fertilizer duration	Additions mean rate (kg-N/ha)	Yield (Tonnes/ha) Max.	Yield (Tonnes/ha) In 1983
Peat-Sand	1971	1971-1974	70	?	0.9
Peat-Sand	1971	1971-1978	80	4.8	0.9
Peat-Sand	1971	1971-1977	167	5.9	1.0
Peat-Sand	1976	1976-1977	80	2.9	1.8*
Peat-Sand	1976	1976-1977	150	3.5	1.2**
Peat-Sand	1976	1976-1978	250	3.9	1.5***
Sand	1980	1980	78	1.1	0.9
Sand	1980	1980-1983	70	1.1	1.1
Peat-Sand	1980	1980	78	2.9	1.5
Peat-Sand	1980	1980-1983	70	2.9	2.2
Peat-Sand-Overburden	1980	1980	78	2.9	2.1
Peat-Sand-Overburden	1980	1980-1983	70	2.9	2.5

Notes:
Information taken from Rowell (1984). The maximum yield refers to maximum above-ground dry matter production while fertilizers were being applied. Starting date refers to the year when the site was seeded. Measurements made in 1983 included three areas in the third experiment where fertilizers were still being applied.

* At this time was a mixed grass and legume cover.
** At this time was a mixed grass cover, mainly Brome.
*** At this time was a monoculture of Brome grass.

TABLE 2

SOME EXAMPLES OF NITROGEN TEST METHODS

Type	Description
1. Direct Biological	
Aerobic incubations	25-35 deg.C, 14-100 days ammonium + nitrate
Anaerobic incubations	30-40 deg.C, 7-21 days ammonium
2. Indirect Biological	
Soil respiration	carbon dioxide
Soil biomass	bacteria
3. Direct Chemical	
Residual mineral-N	ammonium + nitrate
Extraction with acids	ammonium
Extraction with bases	ammonium, total-N
Oxidization	ammonium
Water	total-N
Neutral salts	ammonium, total-N
(All the above carried out using hot and cold solutions)	
Total nitrogen	Kjeldahl
4. Indirect Chemical	
Hot water extraction	organic-C
Barium hydroxide ext.	glucose
Potassium sulphate ext.	glucose
Oxidizing agents	carbon dioxide
Calcium chloride or sodium bicarb, extr.	UV absorbance
Organic matter	
Organic carbon	
Texture	

soils seems more appropriate (Stanford et al., 1973; Stanford and Epstein, 1974). It is found that the formation of inorganic nitrogen under aerobic conditions approximates to a first order kinetic reaction where:

$$Nt = No\,(1 - e^{-kt})$$

No= Potentially mineralizable-N (ug/g)
Nt= Net N mineralized in time t (ug/g)
t= Incubation time in weeks
k= Rate constant

Relationships between the rate constant and net mineralization, and temperature and moisture seem to approximate mathematically to rather simple relationships. Hence a knowledge of No, and the velocity of mineralization as a function of temperature and moisture should allow a prediction of nitrogen release under field conditions. This approach has been followed by several researchers including a study by Campbell on the major zonal soils of the Canadian Prairies (Campbell et al., 1984)

Unfortunately it has been found that the results of laboratory studies on mineralization potential correlate in an increasingly poorer fashion as comparisons are made with other laboratory methods, with greenhouse trials, and with field experiments. For instance, recent work by Fox and Piekielek (1984) for Corn growth in Pennsylvania showed a good correlation between chemical and biological tests such as anaerobically mineralized nitrogen and boiling 0.01M calcium chloride extractable nitrogen. However, correlation of these laboratory measurements with apparent plant uptake of nitrogen released from soil nitrogen reserves were significantly poorer.

This paper presents the results from a study to evaluate some possible soil test methods for nitrogen assessment in agricultural soils from British Columbia.

METHODS

A set of 53 soils was selected from farm soils analyzed in our laboratory during 1984. The soils were selected on the basis of organic matter content which varied from 1.0% to 71.2%. Soil pH varied between 3.74 and 8.08. Most soils were from the Lower Fraser Valley though some came from the more arid Interior and from Vancouver Island. The intended crops were largely corn and grass for silage or grass for pasture though several were for vegetable production.

Nine tests were carried out which were hoped to be directly or indirectly related to nitrogen release. The tests are outlined in Table 3.

A growth chamber experiment was carried out using 30 of the soils with barley as the test plant.

TABLE 3

TESTS CARRIED OUT TO ASSESS NITROGEN MINERALIZATION POTENTIALS OF SOILS

Test Performed	Reference
1. Residua] mineral nitrogen 2M KCl; ammonium and nitrate	Bremner, 1965a
2. Autoclavable nitrogen 0.01M calcium chloride; ammonium after 16 hrs., 121 deg.C	Stanford and Smith, 1976
3. Aerobically mineralized-N 35 deg.C, 14 days, 0.3 bar; ammonium and nitrate	Stanford and Epstein, 1974
4. Anaerobically mineralized-N 7 days, 40 deg.C, saturated; ammonium	Keeney and Bremner, 1967
5. Total nitrogen Kjeldahl ; ammonium	Bremner, 1965b
6. Loss on ignition 420 deg.C, 4 hours, weight loss	
7. Organic carbon dry combustion, Leco furnace; carbon dioxide	
8. Carbon:Nitrogen Ratio from results of 5 and 7	
9. Bulk Density uniformly packed cyclinder of dried ground soil	

Allowance is made for residual mineral nitrogen in methods 2, 3 and 4.

RESULTS

All the laboratory methods studied correlated well with each other when analyzed by linear regression curve fitting methods. Table 4 shows the range and mean for each measurement. Table 5 presents the correlation coefficients (r squared) between each set of paired tests.

Residual mineral nitrogen gave the poorest correlation with other tests. Other direct measurement such as total nitrogen, aerobic-N, anaerobic-N and autoclavable-N were well correlated. However, these were equally well correlated with estimates of organic matter such as organic carbon and loss on ignition. The highest correlations were obtained between organic carbon, loss on ignition and total nitrogen.

It is interesting to note that with the aerobic test, the results could be grouped depending upon the mineralization pattern. Some 69% of the samples tended to accumulate ammonium nitrogen far in excess of nitrate while 18% accumulated nitrate in great excess of ammonium. The remaining 13% produced ammonium and nitrate nitrogen in roughly equal concentrations. These findings could be important in determining types of nitrogen fertilizers to be added as well as in speculation of nitrogen losses from soils.

The results of the growth chamber experiment (Tables 6 and 7) show that both plant dry matter production and nitrogen uptake were strongly linearly correlated with all the tests carried out. The poorest correlations were shown by autoclavable-N and residual mineral nitrogen. The better showing of the residual mineral nitrogen test in relation to its inter-test comparison is of interest. This suggests that mineral nitrogen actually present at seeding may be relatively more important to plant growth than mineral nitrogen that hypothetically would be released at a later date.

In general, tests involving a direct assessment of nitrogen were better correlated with nitrogen uptake than dry matter production. By contrast, indirect measurements such as organic carbon and loss on ignition gave equivalent correlation with dry matter and nitrogen uptake. The same was also true of total nitrogen.

As estimates of plant uptake of nitrogen organic carbon, loss on ignition, total nitrogen and aerobic nitrogen were ranked as equal. Organic carbon, loss on ignition and total nitrogen were the best indicators of dry matter yield.

Dry matter production and nitrogen uptake were also highly correlated with the sum of the amount of mineral nitrogen present initially and that expected to be mineralized during the growth period. The latter was calculated from the results of the aerobic incubation test with allowance made for the temperature during the growing period. However, the linear relationship indicated that much less nitrogen was taken up by the plants than was predicted to have been produced. This seems to suggest that

TABLE 4

RESULTS OF 8 TESTS TO ASSESS NITROGEN MINERALIZATION POTENTIAL OF 53 SOILS

Soil Test Method	Range	Mean
Residual mineral-N (ppm)	3-131	32
Autoclavable-N (ppm)	20-564*	179
Aerobic incubation (ppm)	18-686*	114
Anaerobic incubation (ppm)	17-394*	120
Total nitrogen (%)	0.05-2.46	0.46
Organic carbon (%)	0.55-40.0	6.51
Loss on ignition (%)	1.62-68.8	13.2
C : N ratio	10.0-22.6	14.2

*Residual nitrogen content subtracted.

TABLE 5

LINEAR REGRESSION COEFFICIENTS FROM COMPARISON OF THE RESULTS OF SEVEN SOIL TEST METHODS

	TOT-N	AERB	ANAER	RES-N	AUTO	ORG-C	LOSS
TOT-N		0.81	0.74	0.36	0.76	0.95	0.98
AERB	0.81		0.70	0.38	0.58	0.79	0.81
ANAER	0.74	0.70		0.23	0.81	0.72	0.74
RES-N	0.36	0.38	0.23		0.23	0.33	0.32
AUTO	0.76	0.58	0.81	0.23		0.78	0.79
ORG-C	0.95	0.79	0.72	0.33	0.78		0.99
LOSS	0.98	0.81	0.74	0.32	0.79	0.99	

Total of 53 Soils
All results significant at 5% level

TABLE 6

DRY MATTER PRODUCTION AND NITROGEN UPTAKE OF BARLEY IN A GROWTH CHAMBER EXPERIMENT USING 30 SOILS

	Dry Matter Production (g/1000 g of Soil)		Nitrogen Uptake (mg-N/100 g Soil)	
	Range	Mean	Range	Mean
Tops	0.74-11.1	2.42	17.2-256	63.2
Roots	0.79-5.98	1.91	11.1-113	37.0
Total	2.28-17.1	4.33	28.8-369	100.2

Growing Conditions:

30 soils
Barley test plant
16 hour light period, 23 deg.C day, 15 deg.C night.
Supplementary phosphorus and potassium given.
No nitrogen supplied.
29 day growth period.

TABLE 7

LINEAR REGRESSION CORRELATION COEFFICIENTS BETWEEN SOIL TESTS OF MINERALIZATION POTENTIAL AND DRY MATTER PRODUCTION AND NITROGEN UPTAKE

	Plant Nitrogen	Dry Matter
Organic carbon	0.88	0.88
Loss on ignition	0.88	0.88
Total nitrogen	0.87	0.86
Aerobic incubation	0.87	0.81
Anaerobic incubation	0.73	0.62
Residual mineral-N	0.68	0.61
Autoclavable-N	0.63	0.54

All results statistically significant at the 5% level of significance.

moisture, temperature and aeration affected mineralization differently in the aerobic incubation test and the subsequent growth experiment.

CONCLUSIONS

We may conclude that most of the tests studied correlated well with each other.

Residual mineral nitrogen was rather poorly correlated with other tests.

Autoclavable nitrogen, residual mineral nitrogen and aerobically produced nitrogen were fairly well correlated with plant dry matter production and nitrogen uptake in a growth chamber experiment.

The best correlation with plant growth was found with organic carbon, total nitrogen, loss on ignition and the aerobic incubation method.

In terms of an inexpensive and apparently effective test, loss on ignition would be proposed as a suitable test to estimate plant dry matter production.

However, considerably more field calibration studies would be needed to suggest how the results of such a laboratory test could be used to produce recommendations related to nitrogen fertilizer requirements or the long-lasting suitability of soil materials in mine reclamation.

Baseline interpretations would have to take into account vegetation uptake requirements and the likely extent of mineralization under projected conditions of temperature, moisture arid aeration with the soil.

Within Alberta and British Columbia there is probably enough data of this type accumulated from land reclamation studies to allow a preliminary testing of this hypothesis.

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