1974

Nitrogen Erosion and Fixation in Cool Desert Soil-Algal Crusts in Northern Utah

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1973 PROGRESS REPORT
[FINAL, PART I]

NITROGEN EROSION AND FIXATION IN COOL DESERT SOIL-ALGAL CRUSTS IN NORTHERN UTAH

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US/IBP DESERT BIOME
RESEARCH MEMORANDUM 74-37

Reprint from Reports of 1973 Progress, Volume 3: Process Studies
Microbiological Section, pp 27-44

1973 Proposal No. 2.3.4.2.

MAY, 1974

Citation format: Author(s). 1974. Title
US/IBP Desert Biome Res. Memo 74-37 18 pp.

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ABSTRACT

Using *in situ* nitrogen fixation techniques, precipitation and runoff measurements and total soil-nitrogen measurements, estimates of the nitrogen flux in interspaces of various shrub- and grass-dominated communities of the Curlew Valley were obtained. Nitrogen fixation by the algal crust of the interspaces varied with moisture and temperature. The length of day was important but some fixation during the dark was observed. A model incorporating temperature and soil moisture was used to estimate nitrogen fixation of less that 10 kg/ha year.

INTRODUCTION

Soil Algae and Soil-algae Crusts

Although the properties and ecology of algae in the aquatic environment have been well studied, algae in soil have been largely ignored. Soil algae have been shown to be important to soil fertility, adding nutrients such as carbon and nitrogen as well as providing structure and binding of the soil surface (Shields and Durrel, 1964). Booth (1941) described the role of soil algae in the formation of soil crusts in badly eroded, abandoned farm land. His work showed that this algal crust reduced erosive loss of soil by a factor of 22 when compared with plots denuded of algal crust protection. He also demonstrated that water infiltration through the crust was not significantly altered as it is by crusts formed by the impact of rain.

Fletcher and Martin (1948) studied similar crusts formed in arid areas of Arizona. They showed that this crust aided in erosion inhibition and seed germination. In addition, they were the first to point out that the algae must be involved in nitrogen fixation in the crust. The algae growing in these crusts were members of the Cyanophyceae, including *Nostoc.*

The cool desert in Curlew Valley, Utah-Idaho, has a soil crust composed of soil particles, algal strands and lichen thalli. This soil crust contains microflora capable of fixing nitrogen from the atmosphere. It is the goal of this study to determine the rates of nitrogen fixation by undisturbed crust, to measure the effects of precipitation runoff water action on the nitrogen in the surface soil, and to relate these parameters to observations of nitrogen flux in the soil crust. It should be pointed out that the nitrogen cycle is not always completed through classical mechanisms (Painter, 1970; Nicholas. 1963). For example, in the desert soils of Curlew Valley, it is likely that much of the nitrogen is lost by ammonia volatilization, a physical process (Skujins and West, 1973).

Nitrogen Fixation

Nitrogen Fixation in the Soil by Algae

In the mid 1880's, while early work with legume associated nitrogen fixation was underway, it was discovered that the surface layers of moist sand exposed to light increased in nitrogen content. This addition of nitrogen was attributed to nitrogen fixation by algae growing on the surface. This early report of soil-algae nitrogen fixation was disputed when later investigators working with pure cultures of green algae (Chlorophyceae) were unable to show nitrogen fixation in sterile sands until soil organisms were added. It was then thought that the nitrogen fixation was by bacteria stimulated by the presence of algae (Ashby, 1907).

Nitrogen Fixation by Blue-green Algae

More recent work has shown the involvement of blue-green algae in nitrogen fixation. Fogg and Wolfe (1954) list 42 species of Cyanophyceae that are capable of fixing nitrogen. Most known nitrogen fixers are heterocystous members of the Nostocaceae, Scytonemataceae, Stigonemataceae or Rivulariaceae (Fay et al., 1968). The abundant existence of these organisms in arid soils of Northern Utah (Lynn and Cameron, 1972) indicates that they are important in the nitrogen economy of this environment.

Nitrogen Fixation in Blue-green Soil Algae and Lichens

Blue-green algae that are capable of fixing nitrogen have been isolated from soils in several areas in the world. Granhall and Henriksson (1969) report finding nitrogen-fixing blue-green algae in half of the Swedish soils they studied. They found these algae most commonly in alkaline clay soils. Granhall (1970) also reports the ability of isolated species of these algae to reduce acetylene. Studies in some New Zealand soils (Line and Loutit, 1971) have not revealed the presence of nitrogen-fixing algae.

Lichens containing *Nostoc* phycobionts are known to fix nitrogen (Millbank, 1972; also Henriksson, 1971). These algae excrete nitrogenous products (Henricksson, 1957) which are available to the mycobiont of the lichen and probably find their way into the soil and into other plants. (See also Mayland and McIntosh, 1966.)

Nitrogen Fixation in Arid Lands

Some work has been done on the nitrogen-fixing ability of desert algal crust. Mayland et al. (1966) report the ability of crust organisms to fix 0.11 to 0.19 kg N/ha/day. Evidence of N^{15}-ammonia volatilization was also found. McGregor and Johnson (1971), using the acetylene reduction assay, report the ability of desert algal crusts to fix nitrogen at a rate of 3 to 4 g N/ha/hr after rainfall at 38 C.

Alexander (1971) has measured 3.37 kg/ha/yr nitrogen fixation in arid Australian soils.

Farnsworth and Clawson (1973) report symbiotic nitrogen fixation by sagebrush (*Artemisia ludoviciana*) nodules during spring months. It is possible that other organisms in arid environments will be shown to be nitrogen fixers.

Application of the Acetylene-Ethylene Assay for Measuring Nitrogen Fixation

Schollhorn and Burris (1966) observed that acetylene was a competitive inhibitor of nitrogen fixation, and Dilworth (1966) reported the reduction of acetylene to ethylene by nitrogenase. Hardy and Jackson (1967) suggested that this ability of nitrogenase to reduce acetylene to ethylene coupled with sensitive gas chromatography for ethylene could be used as an assay procedure for nitrogen fixation. A good general outline of the principles involved in the reduction of acetylene to ethylene by nitrogenase is give by Hardy et al. (1973).

There has been an exponential rise in the volume of literature dealing with the acetylene-ethylene assay since 1966 (see review by Hardy et al., 1973).

SITE DESCRIPTION

Curlew Valley

Curlew Valley is part of the Great Basin Desert, the largest desert in the United States. It is a semi-arid cool desert. The valley comprises approximately 3,460 km^2 astride the Utah-Idaho border. The major portion of this study was conducted in the southern part of the valley.

Annual average precipitation in the southern part of the valley is about 25 cm (Balph, 1972). The study year, 1972-73, had an average of about 32 cm of precipitation (Table 1). There was an apparent increase in precipitation, as measured with fencepost raingauges, from the southern study sites to the northern sites, i.e., with distance from the Great Salt Lake (see Balph, 1972). Temperatures range from near 40 C in July to -30 C in January. Radiant cooling at night effects a 15-20 C day-night temperature differential (Balph, 1972).

Table 1. Total precipitation at the study sites (Sept. 30, 1972-Sept. 27, 1973).

Site	Precipitation, cm
1	26.4
2	29.3
3	31.6
4	36.7
5	35.0
6	33.5
7	34.0
mean	32.4

Sampling Sites

Seven sampling and runoff sites were located within Curlew Valley (Figure 1). These sites were numbered consecutively as they were established.

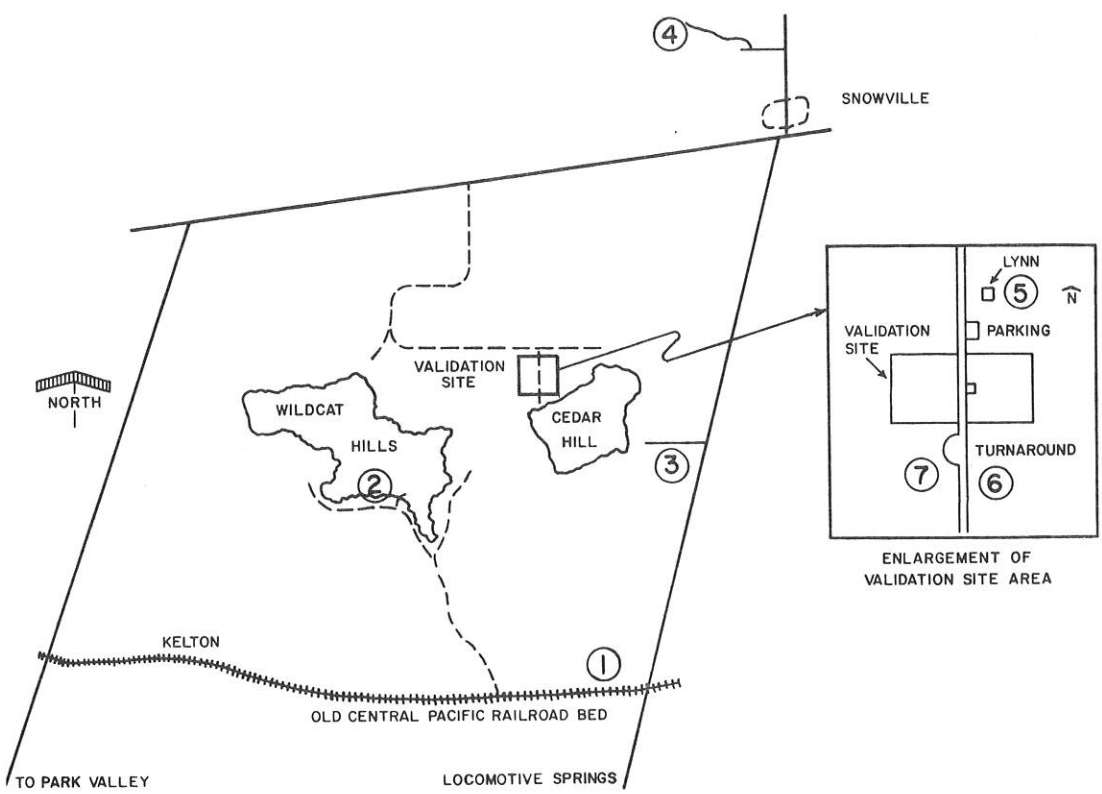

Figure 1. The location of study sites in Curlew Valley.

Site 1. — Sites 1 and 2 were established May 25, 1972. Site 1 is approximately 30.5 m north and 91.5 m west of the intersection of the old Central Pacific railroad bed north of Locomotive Springs. This is a greasewood (*Sarcobatus vermiculatus*) dominated community. The soil crust is fairly well defined and is generally free of lichens. Only sparse growth of grasses occurs.

Site 2. — Site 2 is located on the southwest slope of the Wildcat Hills, approximately 2.95 km north and west of bench mark XX89-1934 in section 8: T-12N-R-10W of the Kelton Pass quadrangle. This area is dominated by a shadscale (*Atriplex confertifolia*) community. The soil crust is fairly well defined and is heavily covered with lichens. The soil is rocky and is only about 0.5 m deep at this site, ending in shale bedrock.

Site 3—Site 3 was set up May 31, 1972, approximately 10.2 km north of the intersection of the old Central Pacific railroad bed and the Locomotive Springs road described above, approximately 915 m west of the Locomotive Springs road along an unimproved dirt road. The area is dominated by a sagebrush (*Artemisia tridentata*) community. The soil crust is very well defined and heavily covered with lichens.

Site 4—Site 4 was established in Idaho, north of Snowville, Utah, on August 11, 1972, as a comparison site distant from the other sites in the southern part of the valley. It was established in the USDA national grasslands area. Runoff plots and soil sampling sites were in the South 13 field inside a sharptail grouse experimental enclosure. The area is dominated by a thick growth of crested wheatgrass (*Agropyron cristatum*). The soil crust is not well defined and is generally free of lichens. This site had not been subjected to grazing for several years.

Site 5 —Sites 5, 6 and 7 were established September 13, 1972, in the area of the US/IBP Desert Biome Southern validation site (Balph, 1972). Site 5 lies about 65.5 m north of the northern boundary of the validation site and 16.5 m east of the road which leads past the weather station on the site. This site is dominated by sagebrush and shadscale. The soil crust is well defined and largely covered by lichens (Pearson, 1972).

Site 6 - Site 6 lies approximately 91.5 m south of the southern boundary of the validation site and to the east of the weather station road. This area is dominated by moderate growth of crested wheatgrass. Lichenous growth is sparse, and the soil crust is moderately well defined. Some cattle grazing is allowed in this area.

Site 7 - Site 7 is in the same proximity to the validation site as Site 6. It lies to the west of the weather station road and is approximately 131 m west of Site 6. This area is dominated by sagebrush and shadscale with an understory of halogeton (*Halogeton glomeratus*). The soil crust is not well defined and lichen growth is sparse and not uniform.

At each site, runoff and sampling plots were arranged as shown in Figure 2. The boundaries of the plots did not allow water to run onto the plot. Only minor variations of this design occurred at the various sites. At Site 4 the fence existing around the sharptail grouse experimental area was used to keep out large animals, but was otherwise similar to the other sites.

METHODS

Collection of Field Data

Sampling was generally carried out on a weekly or bi-weekly basis. Surface soil samples and runoff water were collected and field observations made.

Soil temperature and moisture were measured at each site visited on each sampling date. Soil temperature was taken with a glass bulb thermometer (degrees C) or steel dial reading thermometer (degrees F). Calibration of the dial thermometer showed it had a reading error of ± 3%. Conversion from Fahrenheit to Centigrade temperature was made for data uniformity.

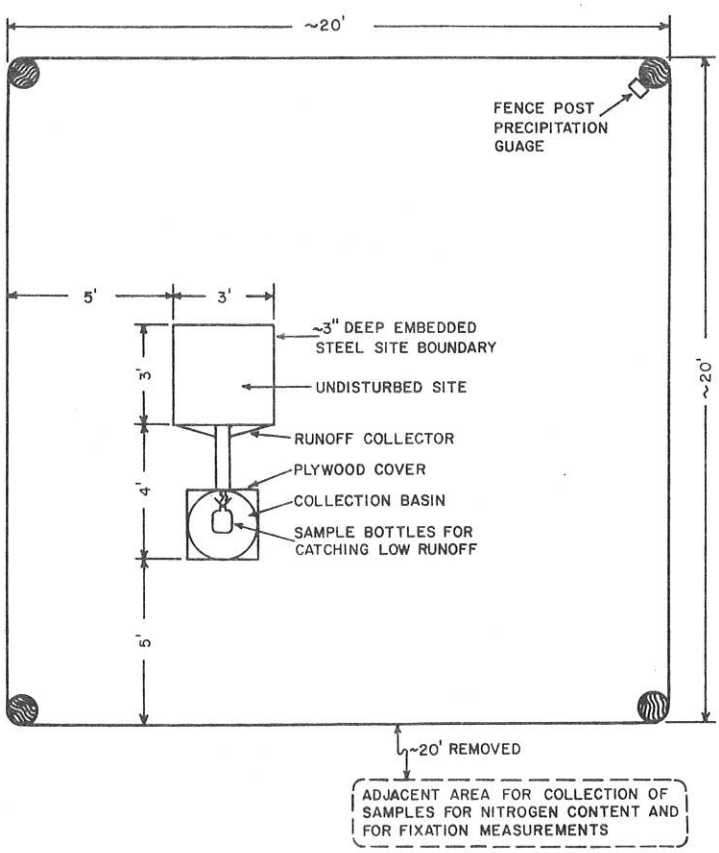

Figure 2. Overhead view of site layout for runoff collection.

Soil moisture was measured using the carbide-acetylene method (Parks Speedy Moisture apparatus). The pressure of the evolved acetylene gas from a given weight of sample, ground and mixed with calcium carbide, is converted directly to soil moisture percent by weight. Laboratory comparison of this apparatus to gravimetric techniques (drying at 105 C) showed the "Speedy" instrument had an average high reading of 2.4%. For purposes of our study, this error was considered to be insignificant in field measurements. In laboratory studies in which the "Speedy" was used, this error was corrected. The relationship of soil moisture to soil water potential in Curlew Valley soils was determined (see Sorensen, 1974) to be: moisture fraction = 2.16 (soil water potential)$^{-1}$ + 0.089.

Accumulated rainfall since the last sampling site visit was recorded on each sampling site. This rainfall was measured using Truchek fencepost rain gauges. A small amount of Rinder oil was added to the gauge to retard evaporation. During winter months a small amount of dilute commercial anti-freeze was also added to prevent freezing of collected precipitation and breaking of the plastic gauge. General weather conditions were also noted on each site visit.

Measurement of Standing Crop Nitrogen

All determinations of standing crop nitrogen were made on an areal basis so that this data would better coincide with studies in other communities of the desert ecosystem. Thus, samples were taken with a number 8 cork borer (circular area of 1.89 cm^2) to a depth of 1 cm. Five such cores were taken at random within a staked-off area adjacent to each fenced runoff collection site described above. These cores were composited in a plastic bag (Whirlpack), transported to the laboratory and frozen until analysis was performed.

Before analysis, the sample and the plastic bag were weighed and the average weight of the bag (4.001 g ± 0.01 g) was subtracted from the total to give the net weight of the sample.

The sample was then pulverized and thoroughly mixed in the bag. A sub-sample of this composite sample (usually 100 mg or more) was then analyzed for total nitrogen. All analyses were done with undried samples to avoid loss of any volatile nitrogenous compounds. Weighing of the sub-sample was done as quickly as possible ($<$30 sec) on a single pan analytical balance. Weight loss during weighing due to evaporation of moisture was estimated to be insignificant.

Samples were analyzed with a Coleman model 29 nitrogen analyzer, which employs automation of the micro-Dumas nitrogen technique. The precision of the analysis on this machine was good; the analysis of four sub-samples of a sample of Site 5 crust resulted in a coefficient of variation of 5%. An estimation of total nitrogen on an areal basis and a dry weight basis was calculated; the dry weight value was calculated from the areal value by correcting for percent soil moisture.

Measurement of Nitrogen in Runoff Waters

Runoff water was collected at each of the seven sites from the 1 sq. m plots illustrated in Figure 2. Small volumes of water were collected in the smaller bottle inside the polyethylene barrel. Occasionally sufficient runoff was collected to overflow the smaller bottle. In this case both the contents of the smaller bottle and the water which had overflowed were mixed together. The total volume of the runoff was measured, and a 2 to 4 liter sub-sample was taken for analysis. When the volume was very large, as in the case of snow melt runoff, the volume was calculated simply by measuring the depth of the water in the cylindrical barrels. The contents of the barrel were thoroughly mixed and a 2 liter sub-sample taken for analysis. When the depth within the barrels was at the level of the inlet pipe it was assumed that overflow may have occurred. Overflow occurred only during the spring snow melt runoff (Site 3, March 30, 1973; Sites 5 and 6, April 7, 1973).

Ammonia and organic nitrogen concentrations in the runoff water were measured as total Kjeldahl nitrogen as described by Strickland and Parsons (1968). A 10 ml aliquot of well-mixed, unfiltered sample was used for this analysis. Indophenol (Solorzano, 1969) or nesslerization (APHA, 1971) colorimetry was used for ammonia determination after distillation.

A 50 to 200 ml subsample of the runoff water was filtered through a Whatman GF/C glass fiber filter which had been distilled-water washed, dried over night at 103 C and preweighed. The filter and the solids collected on it were dried overnight at 103 C and weighed. Suspended solids were determined from the difference in weight of the filter before and after filtration. The filter and solids were then used to determine total particulate nitrogen in the runoff and the filtrate was used for nitrate plus nitrite determinations.

Nitrate plus nitrite concentrations in the runoff water were determined using the cadmium reduction technique and diazotization colorimetry (Strickland and Parsons, 1968). The sum of total Kjeldahl nitrogen and nitrate plus nitrite nitrogen was assumed to be total nitrogen in the water.

Total particulate nitrogen associated with the runoff water was determined by analysis of suspended solids on the filter (including the filter) in the Coleman nitrogen analyzer.

Nitrogen Fixation

Special chambers, described below, were used for both field and laboratory measurements of nitrogen fixation by the acetylene reduction technique. The general procedure employed was similar to that used by Stewart et al. (1967). Atmospheric nitrogen was removed from the chambers by flushing with a synthetic atmosphere (Matheson Co.) of 0.04% CO_2, 22% O_2 and the balance argon, for 2 min.

This mixture was injected through a 22 gauge hypodermic needle at 8 to 10 psi back pressure and vented through another hypodermic needle or from around a loose-fitting rubber stopper. After flushing was complete, purified acetylene (Matheson Co.) was injected with a 500 ml capacity syringe to make a partial pressure of acetylene of from 0.1 to 0.2 atmospheres. The vent was then closed and incubation begun. However, Hardy et al. (1973) have suggested that a partial pressure of acetylene of 0.02 atm. is sufficient to saturate *in vivo* nitrogenase as would 0.8 atm. N_2. In future work, lesser acetylene concentrations could be used.

Since a small amount of ethylene contaminates the purified acetylene, an initial sample of the gas phase was taken immediately after incubation began and was used as a blank correction for subsequent samples. Samples were removed from the gas phase periodically at 10 to 30 min intervals, transported to the laboratory, and analyzed by gas chromatography for ethylene concentration. Incubation time never exceeded 90 min.

On-going work by Skujins (1974) includes work correlating acetylene reduction by Curlew Valley soil algae crusts to ^{15}N-nitrogen fixation. The relationship between the two techniques has generally been found to be satisfactory.

Field Apparatus for Nitrogen Fixation

To avoid as much as possible the effects of localized concentrations of nitrogen fixing organisms, and the effects of microenvironments, the incubation chamber was designed to cover as large a surface area as was practical. At the same time a sufficiently large gas phase volume was desired so that more than one or two 6 ml samples could be taken out of it without reducing the pressure of the system significantly. The design had to also allow measurement of nitrogen fixing activity of the crust in place so that *in situ* conditions could be maintained as best as possible. Figure 3 shows the apparatus which was used with the most success. Other variations of this design were tried with limited success. The apparatus consisted of a 0.635 cm thick, clear, lucite canopy with a bolt-on 14 gauge steel ring. An "O" ring formed an air-tight seal between the two parts. The inside diameter of the steel ring and the lucite canopy was 15.1 cm.

The steel ring, with or without the attached canopy, was forced into the soil crust inside the vessel. The lucite chamber was then attached if the ring was inserted without it. Water was poured into the water bath atop the chamber when necessary to control the temperature inside the vessel. Ice could be added to the bath if ambient temperatures and solar intensity were high, to prevent heat build-up and to maintain ambient temperatures.

Considerable difficulty was encountered in maintaining the composition of the atmosphere inside the incubation chamber. Gasses were easily exchanged through cracks in the soil around the apparatus. To insure an air-tight seal around the steel ring, large volumes of water were allowed to soak around the outside of the vessel. Eight to 18 liters of water were added and allowed to soak in for approximately an hour before the chamber was closed and flushing began. Water was added periodically to the outside soil throughout

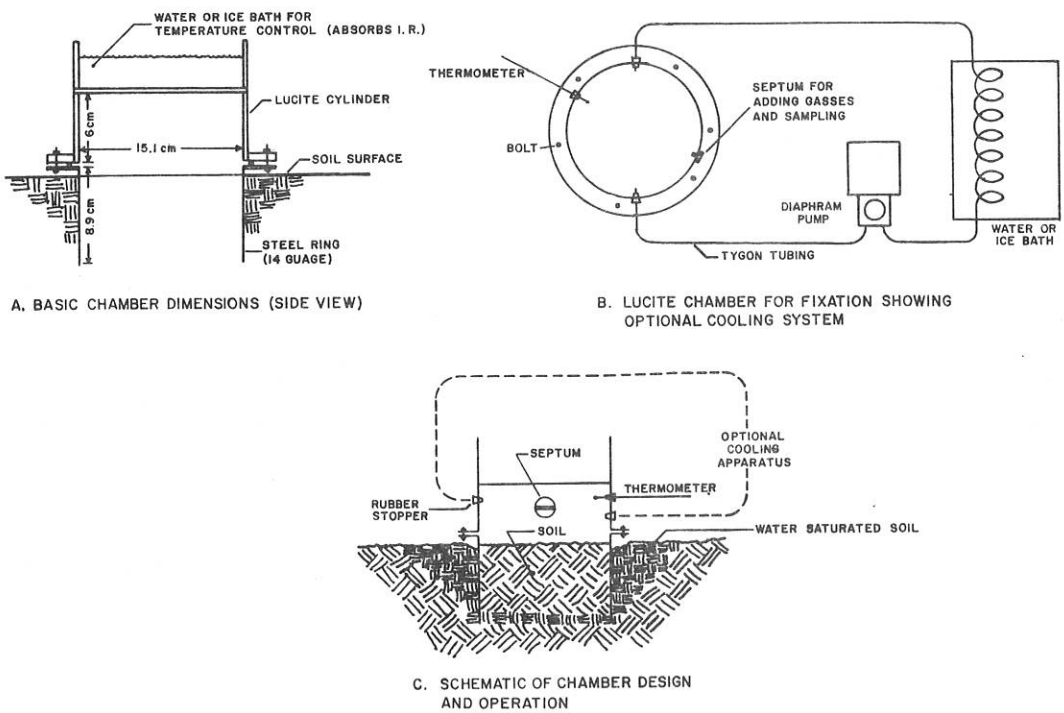

Figure 3. Design of *in situ* Lucite fixation chambers.

the incubation. In our experience, this water never soaked up into the soil core inside the 8.9 cm steel ring more than 2 to 3 cm after several hours; therefore, the added water did not significantly affect the moisture of the soil crust inside the chamber. Using the acetylene peak on the gas chromatogram as an internal standard made detection of leakage in the system simple. All results showing a leak (decrease in acetylene peak size with time) were discarded.

During the development of the apparatus, considerable concern was given to maintaining soil temperature at ambient conditions. Extreme heat build-up occurs when direct sunlight is on the apparatus when the chamber is closed. In the prototype apparatus a thermistor was installed that monitored surface soil temperature and a bulb thermometer monitored chamber air temperature. Invariably, when the chamber air temperature was near ambient temperature, the inside soil surface temperature was near ambient surface soil temperature. It was obvious that if the temperature of the chamber air was monitored and controlled to ambient temperature, the inside surface soil temperature would at the same time be controlled to near ambient conditions. An arrangement for circulating the atmosphere through a heat sink could be employed (Figure 3) if more control of temperature was required than could be attained with an ice bath above the chamber Conditions which required the use of the circulating atmosphere attachment for cooling were seldom encountered when soil moisture was sufficiently high and/or soil temperature was within the range that nitrogen fixation could be detected

Four ½-inch holes were drilled in the walls of the chamber. Two non-opposing holes were used for connection of the circulating atmosphere attachment, and were usually closed with solid rubber stoppers. One was used for insertion of a bulb thermometer, and the other had a septum for adding gasses and removing samples.

During the major portion of the study, gas samples were taken in highly evacuated (0.1 mm Hg) 6 ml nonsterile Vacutainer blood tubes (Becton and Dickinson Co.) and transported to the laboratory. [Sterilized blood tubes contain ethylene] These blood tubes were then subsampled with a gas tight syringe and injected into the gas chromatograph. This method has the advantage of allowing two 0.5 cc samples to be taken from each blood tube before a measurable change in concentration occurs; i.e., if one injection failed in some way, another 0.5 cc sample could be obtained.

The disadvantage of the vacutainer method is that the tubes do not come from the manufacturer with a highly reproducible vacuum. Each tube draws a different volume, and significant dilution of the sample occurs. Because of this, these tubes must be reevacuated and sealed before they can be trusted to give reliable results. We evacuated the tubes through a 26 gauge hypodermic needle to 0.1 mm Hg pressure, and then sealed the tube by dipping it in molten beeswax to about ¼ of the tube length. These tubes maintained an even vacuum for at least 24 hr.

During the last few months of the study, it became obvious that a duplicate of any given sample was seldom necessary. A gas sampling valve is part of the accessories of our gas chromatography system, and allows much better precision for gas sampling than does direct injection. The sampling loops require 1.5 to 2.0 cc of gas to flush and fill the loop to obtain good reproducibility. The loops have a 0.5 cc capacity. By collecting a 3 cc sample in a 10 cc plastic disposable syringe, and then inserting the needle in a rubber stopper, a sample could be maintained for at least 24 hr. This resulted in time saving and improvement in precision. In the last third of the study, all samples from the fixation chamber were collected in this manner.

Gas Chromatography

Analysis of gas phase samples for ethylene concentration was done on a Hewlett-Packard model 5750 research gas chromatograph with a dual flame ionization detector and dual 2.44 m x 0.318 cm stainless steel columns packed with porapack R (Waters Associates Incorporated). The helium carrier gas flow rate was approximately 30 cc/min. Column oven and flame detector temperatures were 50 to 110 C respectively. The gas sampling valve was operated at 40 C.

Calibration of the instrument was done by making dilutions of chemically pure ethylene (Matheson Co.) in known volumes of air. The response of the chromatograph, by peak height, to concentrations of ethylene was found to be linear over a broad range of concentrations. Departure from linearity occurs at very low concentrations. Approximately 1 ppm ethylene (v/v) can be measured with confidence. Making known concentrations of ethylene by the method described above is difficult to duplicate precisely; a 5 ppm ethylene in N_2 standard (Matheson Co.) was purchased and used to verify calibration during the last several months of the project.

Laboratory Nitrogen Fixation Techniques

Laboratory studies of nitrogen fixation were done using an adaptation of the field apparatus. The lucite canopy described above was removed from the steel ring used in the field, and bolted to a 0.476 cm thick aluminum plate. A 1 cm high band of lucite with an outside diameter of 15 cm was glued to the plate in the center so that the canopy fitted around it. This made a well in the plate 14 cm in diameter that could be filled with soil or other substrate.

For studies on the effect of temperature on nitrogen fixation rate it was necessary to have the soil crust moisture at field capacity so that no inhibition of activity could occur due to lack of water availability. To attain this, cellulose sponges were cut to fit the well of the aluminum plate. The sponges were saturated with distilled water and warmed or cooled to the desired incubation temperature. The crust was removed from the dry soil, which had been brought into the laboratory, to a depth of 2 to 5 mm. These pieces of crust were placed on a 14 cm circle of filter paper and the filter paper and crust were placed on top of the saturated sponges.

The crust was than sprayed with atomized distilled water until water began to stand on the surface. The experiment was timed from this point. The lucite canopy was then bolted in place and preincubation treatment begun. Preincubation flushing and injection of acetylene was identical to that described for field studies. Temperature was controlled by incubating in a Precision Scientific low temperature incubator.

Light was supplied by two bench top fluorescent lighting fixtures. One employed two Sylvania F4T5/CW lamps. the other two Westinghouse Daylight F4T5/D lamps. The total light at the crust surface was 250 to 260 ft-c. This level of illuminaton was considered to be in the optimal range for nitrogen fixation (Rychert, 1973).

The effects of moisture were studied under similar circumstances. Moisture content of the soil crusts was varied by mixing distilled water-snow (made by shaving ice cubes in a chilled Waring blender) with pulverized, room dry, chilled-to-below-freezing, surface soil from which the surface crust had been removed. The dry soil (150 to 200 g) was preweighed and sufficient snow added to bring the weight to that of soil of the desired moisture. After careful mixing, the soil was placed in the well on the aluminum plate described above. Crust pieces were added to cover the soil, and the lucite chamber bolted in place with all holes open for ventilation. The apparatus was then incubated. As the soil warmed to 20 C, the snow particles melted, distributing the moisture evenly throughout the soil. Six to seven hr were allowed for the crust to come to equilibrium with the soil before rate measurements were made. After the nitrogen fixation rate was measured, the lucite canopy was removed and the actual moisture of the crust pieces was measured by the "Speedy" moisture method described in field procedures above. An inconsistent relationship was found between the final measured moisture and the "intended" moisture content of the substrate soil. This necessitated measuring the final moisture after each experiment.

RESULTS

Standing Crop Nitrogen

Areal concentrations of total surface soil nitrogen in Curlew Valley are surprisingly uniform. The average of the seven sites' yearly averages is 1.97 mg N/cm^2 with a coefficient of variation of only 14%. All actual tabulated data can be found in DSCODES A3UFA01 and A3UFA02. Other analyses of data not necessary to this report are in Sorensen (1974).

The areal concentrations of nitrogen with time for the seven sites are shown in Figure 4. Examination of Figure 4 indicates that several of the sites show a seasonal increase and decrease in areal concentrations of total nitrogen, being generally higher in the spring and fall but lower in the winter and summer. A statistical comparison by Students t test of the seasonal means of the areal nitrogen concentration data seemed to bear out the fact that nitrogen concentration generally increased in the fall and spring but decreased in the winter and summer. However, when the same test was applied to the percent nitrogen by weight values, the t test showed that only rarely were the seasons

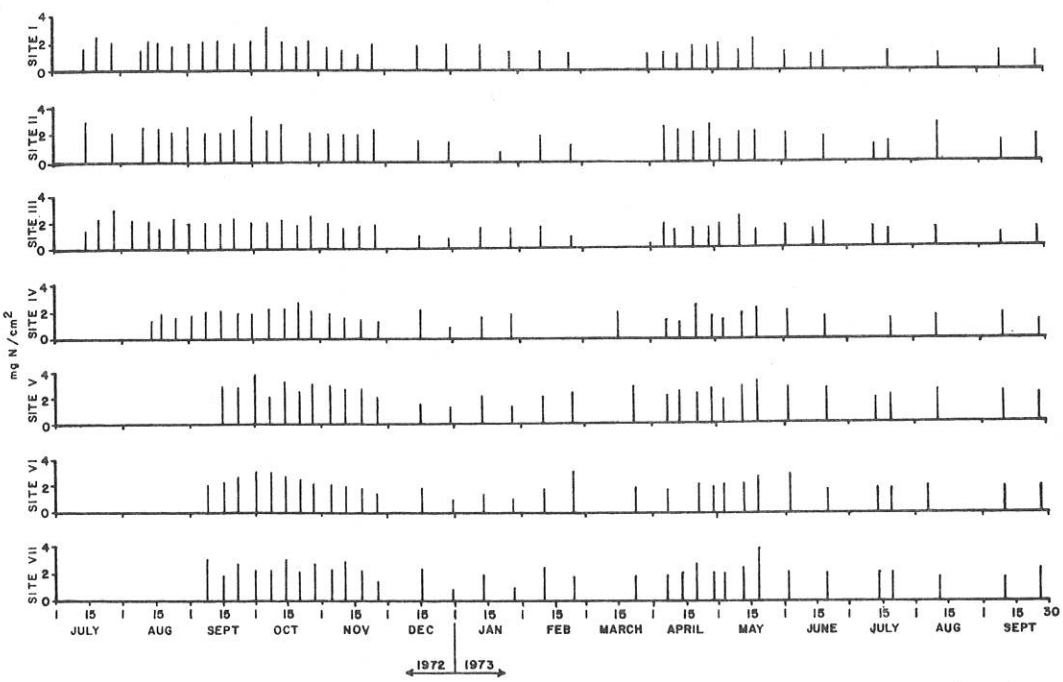

Figure 4. Areal concentrations of surface soil total nitrogen in Curlew Valley with sampling date.

significantly different in value. When a significant difference did occur it was not between the same seasons as the areal analysis indicated.

This discrepancy probably arose from problems in sample collection. Field experience indicated that a perfectly uniform 1 cm deep core of surface soil was easily collected only when the soil was relatively damp and easily compacted. When the soil was very dry, small pieces of soil would drop out of the cork borer before they could be composited in the plastic bag. Occasionally several tries had to be made to collect a core of soil when the soil was dry. This "lightening" of the soil core would cause the amount of nitrogen per area to appear to decrease. During the winter months melting snow caused a thin layer of ice to form over the soil under the snow cover. Removal of this ice was not practiced during sampling since it did not form with a distinct boundary from the soil, but was mixed with the surface. This ice, when melted and mixed with the collected soil, diluted the nitrogen and caused the amount of nitrogen per area to appear to decrease. Since the amount of ice from each sample and with each sampling date varied considerably the coefficients of variation for the winter analyses were unusually high, ranging from 19 to 46% as compared to a range of 11 to 36% for all the other seasons.

These factors cast such a shadow of imprecision over the standing crop nitrogen analysis: it is impossible to say with any certainty that seasonal changes in total surface soil nitrogen could be detected. As will be pointed out below, it is doubtful that nitrogen fixation as measured during this study could account for the large interseasonal changes in nitrogen concentration observed. This is not to say that seasonal changes do not occur, but only that they occur below the level of detectability in the standing crop analysis used in this study. In fact, changes probably do occur and are likely to be that of increase during periods favorable to nitrogen fixation and decrease during periods favorable to nitrification-denitrification, erosive loss and/or ammonia volatilization.

It is evident that there is no build-up of surface soil nitrogen in the areas of Curlew Valley studied here. Nitrogen fixation appears to be balanced with removal processes on an annual basis, and standing crop nitrogen could probably be thought of as being at steady state.

Runoff Waters

The runoff is compared for a ten month period (November 25, 1973, to September 27, 1973) for which simultaneous data for all sites are available (Table 2). Initial samples obtained during the study were not analyzed for nitrogen.

Two of the many factors which affect the relationship between rainfall and runoff are rainfall intensity-duration and infiltration. Runoff occurs when the ground is sufficiently saturated so that further rainfall remains on the surface. Intensity-duration must be great enough to saturate the soil and infiltration governs the rate at which it is saturated. No direct measurements of intensity-duration or infiltration were taken during the study so only inferences based on the observed sites and runoff results could be made.

Site 4 received the most total precipitation during the 10-month period covered in Table 2, yet the total runoff here was less than half that of any other plot. Because of this, far less nitrogen was removed by erosion here than at any other site. The heavy growth of crested wheatgrass here apparently was an excellent medium for stabilizing the soil and improving infiltration of water. There was no definite soil crust at this site, and only occasional lichen growth could be found.

Site 1, which is farthest south in the valley, received the lowest rainfall for the 10-month period, and recorded only three runoff events. A large amount of nitrogen was removed in this runoff due to the easily eroded nature of this surface soil. The algal crust here is not lichenous. Crust structure is given mostly by growth of algae which are members of the Oscillatoriaceae.

Site 2 received nearly the same amount of precipitation and produced approximately the same amount of runoff as Site 1. The amount of nitrogen carried in the runoff is nearly one-third that at Site 1. This site has a definite algal crust which is composed largely of lichens.

Site 3 produced the largest volume of runoff water of any of the sites, but the amount of nitrogen carried was intermediate. The well-structured lichenous crust at this site

Table 2. Summary of runoff water and runoff nitrogen removals, Nov. 25, 1972 to September 27. 1973

Site	Total rainfall during period, cm	Total runoff flow, liters · m^{-2}	Ratio of runoff to rainfall	Total N carried in runoff water, mg·m^{-2}
1	18.8	16.8	0.89	150
2	20.4	16.9	0.83	52
3	23.4	90.5	3.87	150
4	27.4	7.1	0.26	20
5	25.1	86.2	3.44	147
6	23.5	83.1	3.54	256
7	24.4	53.7	2.20	163

undoubtedly provides a good deal of stabilization to the soil. The most interesting observation at this site was the consistantly high concentration of nitrate plus nitrite in the runoff water, averaging 1.92 mg N/1. These high values of nitrate plus nitrite may be evidence of a high level of nitrification at this site (Todd et al., 1973).

Sites 5 and 6 are located within 1.5 km of one another on opposite sides of the southern IBP Desert Biome validation site. Site 6 has been plowed and replanted to crested wheatgrass within the last decade. Runoff volumes from these two sites were approximately the same, and yet runoff from Site 5 carried only 57.5% of the nitrogen in Site 6 runoff. The Site 5 soil is well stabilized by algal crust and lichen growth. Manipulation of Site 6 has destroyed the crust community and left the soil open to erosion. Crested wheatgrass has begun to establish itself, but has not yet achieved a stand sufficient to provide the stabilizing effect it has at Site 4.

Site 7, also located in the southern validation site area, produced 62% of the runoff volume as that at Site 5, but carried 11% of the nitrogen. The crust here is thin and not well defined. Lichens can be found, but they are not as common as at Site 5. Again it appears that the more firmly established the soil-algae crust is, the more effective it becomes in preventing erosive loss of nitrogen from the soil. Figure 5 shows the relationship between suspended solids and particulate nitrogen in runoff waters of Curlew Valley.

Plot boundaries were constructed to prevent any water from running onto the plot. In order to see if runoff water action had actually reduced significantly the areal concentration of nitrogen inside the runoff plot boundaries, a sample of five cores from each plot taken randomly over the entire plot was analyzed. No significant difference in these samples and samples taken adjacent to the plot could be seen. Whatever losses occur due to erosion or leaching are apparently overcome by nitrogen fixation or the loss is below the level of detection of the standing crop methods used.

In Situ Nitrogen Fixation

Data from *in situ* measurements of nitrogen fixation during daylight and night (darkness) hours for Site 5 are contained in Tables 3 and 4, respectively. Most nitrogen fixation activity seemed to occur at temperatures around 20 C and at soil moistures above 5%. An unusually high rate of fixation was encountered October 14, 1972, at Site 5 (see Table 3). Since such a high rate was never encountered again during the study, this measurement likely represents the unintentional selection of an area unusually heavily populated with nitrogen-fixing organisms under nearly ideal conditions for nitrogen fixation (12.8% moisture and 18 C). Since such a "hot spot" was not encountered again during the study, it did not seem likely that a significant portion of the surface soil around Site 5 has the ability to fix nitrogen at this rate.

Results of diurnal nitrogen fixation measurements (Table 4) showed that nitrogen fixation could continue through at least part of the darkness of night. Data from May 18 and 19, 1973, indicated that the rate could actually increase

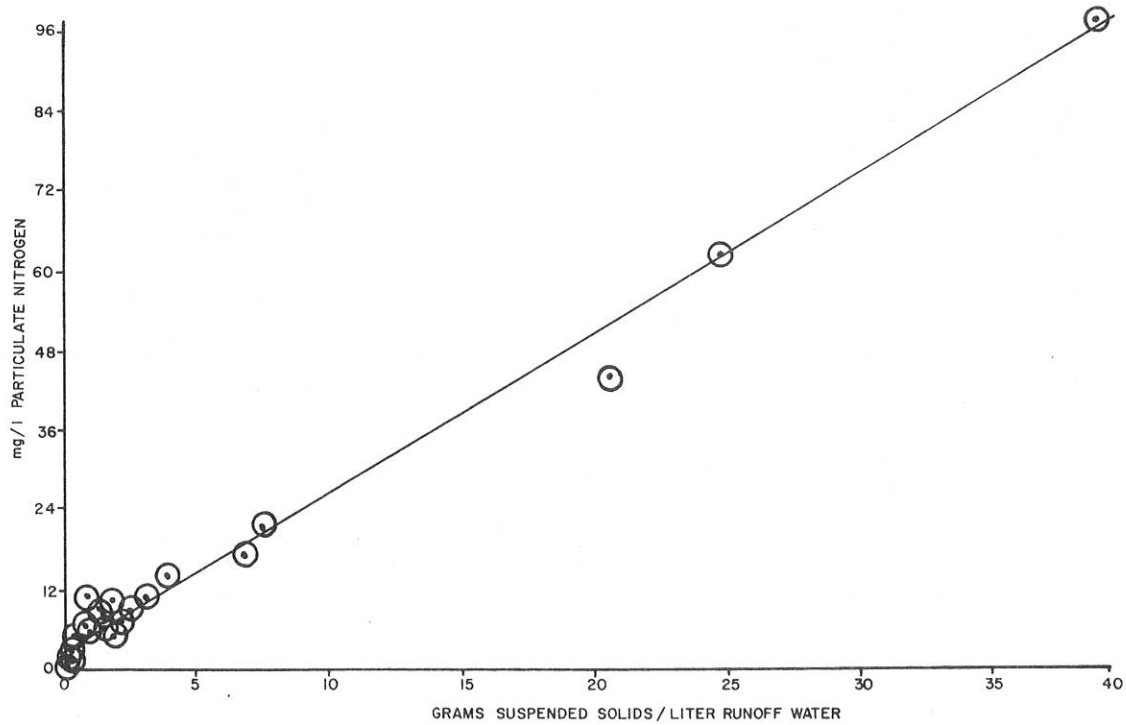

Figure 5. Relationship of total particulate nitrogen to suspended solids in Curlew Valley runoff water.

slightly during early morning hours when the surface of the crust was moistened by dew. Generally it appeared that nitrogen fixation probably decreased gradually through the night as energy reserves (stored ATP) and/or reducing power (such as ferredoxin) was used up (see Tables 3 and 4 data, November 17 and 18, 1972).

Table 3. Daylight *in situ* nitrogen fixation at site 5

Date	Time of Day	Soil Temp. (°C)	Soil Moisture (%)	Fixation Rate (10^{-7} mg$N_2[C_2H_2]$/cm^2 · min)	Comment
9-15-72	1000	30.5	9.0	2.2	
10-14-72	1200	18.0	12.8	15.0	
10-27-72	1600	13.5	-	3.6	
11-17-72	1400	-	-	2.6	
11-18-72	800	-	-	2.6	
11-18-72	1100	8.0	20.0	7.6	
2-10-73	1200	0.0	26.4	0	Rate: <0.12*
2-24-73	1130	0.0	34.5	0.8	
3-23-73	1330	13.5	21.6	4.4	
4-14-73	1500	~25	~03	0.8	
4-21-73	1100	24.0	5.0	0	Rate: <0.21
5-12-73	1300	~30	1.3	0	Rate: <0.26
5-18-73	1730	-	≥05	0.3	
5-18-73	1900	-	≥05	0.5	
6-02-73	1200	22.2	2.0	0	Rate: <0.21
6-15-73	1700	17.2	11.6	6.7	
6-19-73	1945	20.6	3.1	0	Rate: <0.14
9-10-73	1140	24.4	17.8	3.9	
10-11-73	1200	10.0	15.4	4.5	

*Temperature may have been ≤ 0.5° C.

Table 4. Night (dark) *in situ* nitrogen fixation at site 5

Date	Time of Day	Soil Temp. (°C)	Soil Moisture (%)	Fixation Rate (10^{-7} mg$N_2[C_2H_2]$/cm^2 · min)	Comment
11-17-72	2000	≤10	~20	2.11	
11-17-72	2300	≤10	~20	1.3	
11-18-72	200	≤ 5	~20	1.0	
4-14-73	300	2.0	~ 3	0.3	
4-14-73	600	2.0	~ 3	0.4	
5-18-73	2200	-	~ 5	0.3	
5-19-73	230	-	~ 5	0.6	
5-19-73	400	-	~ 5	0.5	
6-20-73	145	8.9	5.1	0	Rate: <0.14

Laboratory Nitrogen Fixation

The requirement for moisture by nitrogen fixing organisms in the Curlew Valley desert soil was immediately obvious from *in situ* measurements. A question arose about the response of the nitrogen fixers to the application of moisture to the surface soil such as during a rain event. Application of moisture to Site 5 crust gave the results shown in Figure 6. Various temperatures of incubation gave various nitrogen fixation responses as time elapsed since wetting of the crust.

At higher temperatures (20 C and 31 C) activity increaed rapidly after wetting to some maximum value and then began to decrease as the incubation was continued over 24 hr. The activity at lower temperatures (10 C to 15 C) increased more slowly and appeared to approach some plateau but no decrease in rate was observed during the incubation. The bargraph inserted in Figure 6 shows the rates of nitrogen fixation of Site 5 crust incubated at 10 C when placed on a 12-hr dark cycle. The level reached after the second and third 12-hr light day was approximately that reached at 850 minutes or 14 hours of continuous light. This indicated that wetting the crust at low temperatures, such as those encountered in late fall or early spring, did not bring the crust to "maximum" nitrogen fixation levels for as much as two light days following the rainfall event.

The results of incubating Site 5 crust at 20 C and various moisture contents are shown graphically in Figure 7. Computerized non-linear curve fitting techniques (Grenney, 1974) fit the data with the hyperbola shown in Figure 7. This function suggests first order, zero order kinetics for the response of the nitrogen fixing mechanism to available water, thus indicating Michaelis-Menton kinetics. The data scatter was probably due largely to microenvironmental variations in nitrogen fixer population and/or other limiting factors.

Table 5. "Optimum" nitrogen fixation at various sites in Curlew Valley

Site	Nitrogen fixation rate 10^{-7}mg $N(C_2H_2)$ · cm^{-2}min^{-1}	Visual & microscopical characterization
1	3.6	Well defined crust; some Nostoc; essentially no lichens.
2	3.5	High lichen; Nostoc high; well defined crust.
3	9.2	High lichen; Nostoc high; well defined crust.
4	0.26	Lacks lichens and a well formed crust; few Nostoc.
5	6.2	High lichen; Nostoc high; well defined crust.
6	1.9	Well defined crust; some Nostoc; essentially no lichens.
7	0.76	Lacks lichen and a well defined crust; few Nostoc.

Microscopic Observations

In order to more closely characterize the nitrogen fixing organisms in the crusts of Curlew Valley, direct microscopic

examination of bits of crust was made. Pieces of lichen thalli and non-lichenous crust from Site 5 were closely examined by transmitted light microscopy for heterocystous algae. Many species of algae were observed from several samples. Members of the family Oscillatoriaceae including large numbers of *Microcoleus* sp. were observed in every sample. Other algae frequently observed were *Trebouxia* (associated with lichen thalli) and many genera of diatoms.

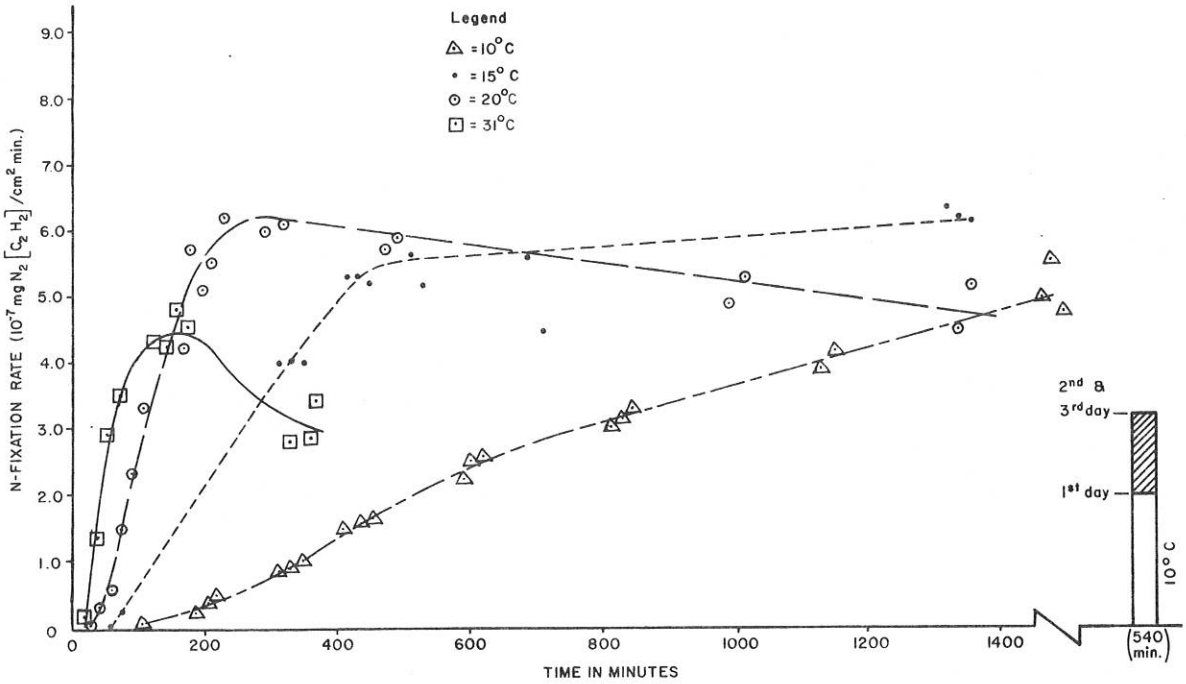

Figure 6. Nitrogen fixation rates at various temperatures varying with time after wetting (site 5 crust).

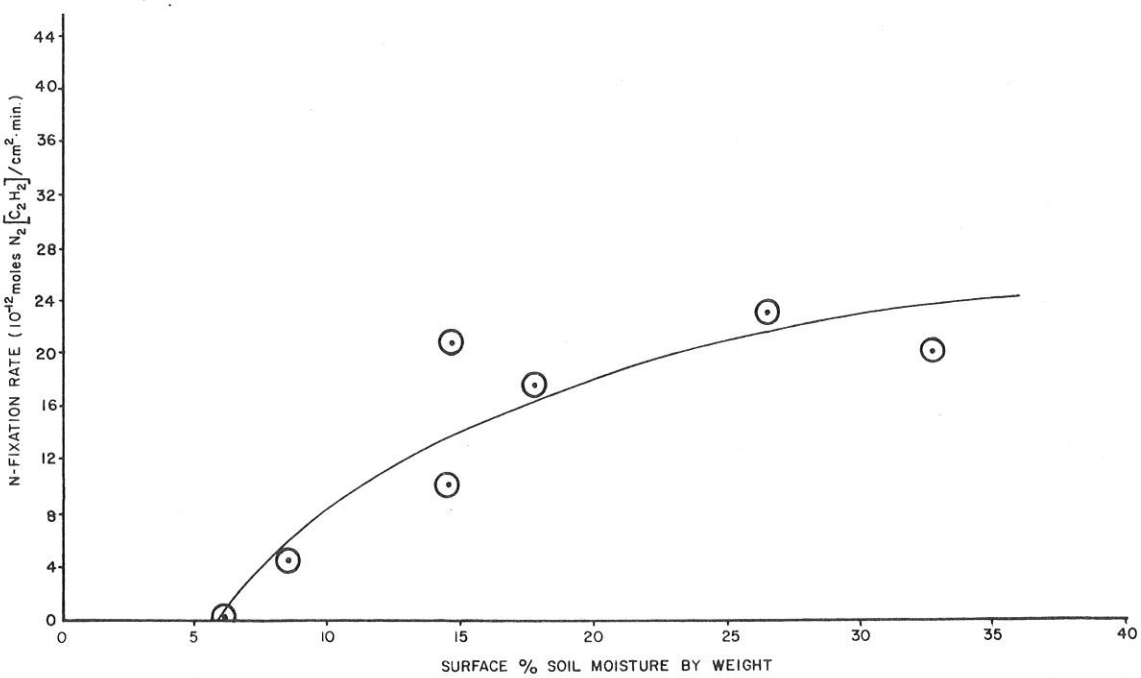

Figure 7. Nitrogen fixation rate has hyperbolic relationship to moisture at 20 C after 6-7 hr preincubation.

Heterocystous algae were not observed until opaque spherical structures often entwined in the lichen thalli were broken open. These spherical bodies proved to be colonies of *Nostoc* sp. which contained many heterocysts.

Examination of pieces of soil crust under epiflourescent microscopy readily revealed the fluorescing red color of chlorophyll of the algae on the surface of the soil. With this technique colonies of *Nostoc* were easily seen without the trouble of removing them from the surrounding soil community. Figure 8 shows a photomicrograph of a piece of Site 5 crust including a colony of *Nostoc*. Examination of a few pieces of crust from each site by epifluorescence made a qualitative evaluation of the population of *Nostoc* very simple and quick.

Crust from Sites 2, 3 and 5, the sites most heavily colonized by lichens, showed the most dense population of *Nostoc* colonies under epifluorescent microscopy. Sites 4 and 7, which are practically barren of lichens and lack a well formed crust, were least populated by *Nostoc*. Sites 1 and 6, which have a well defined crust but are nearly lichen free, were intermediately populated with *Nostoc* colonies. Examination of Table 5 shows that the populations of *Nostoc* observed corresponds with the "optimum" nitrogen fixation rates of crust from the various sites.

Surface soil crusts from all seven sites were assayed for nitrogen fixing ability under laboratory conditions which were considered to be optimal (20 C, field capacity moisture, and 250 to 260 ft-c illumination) for nitrogen fixation. The "optimum" rate after 6 hr preincubation for crust from each site is listed in Table 5. The relative nagnitudes of the nitrogen fixation rates observed here are similar to those of the population of *Nostoc* colonies observed in samples of crust from each site by epifluorescent microscopy.

DISCUSSION

Standing Crop Nitrogen

Concentrations of nitrogen in the surface soils of Curlew Valley appear to be at steady-state. This is not surprising since the ecology of the Great Basin desert is more than likely that of a climax community. Rapid changes in the structure of any of the vegetative communities in the Great Basin are rare, and it is unlikely that the microbial community is in a state of rapid flux. Small seasonal changes in nitrogen concentration in the surface soil may exist below

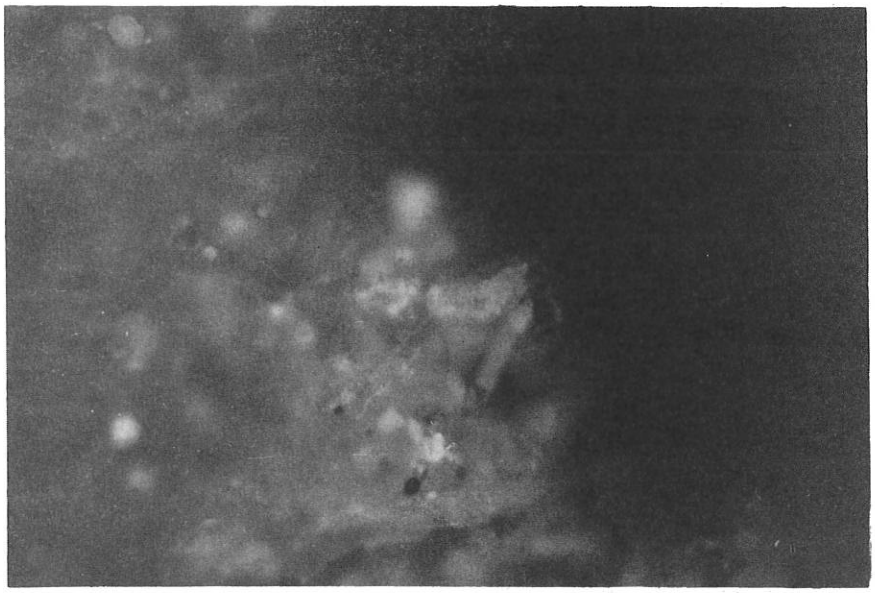

Figure 8. A photomicrograph using epifluorescence technique of site 5 crust (160 X). Features in the photomicrograph are identified in the sketch below it as: O indicating an alga of the Oscillatoriaceae, N is a colony of *Nostoc* sp., F indicates the location of fungal mycelia, and M is a fluorescing soil mineral crystal.

our level of detection.

Runoff Waters

Erosion and leaching from precipitation runoff have little net effect on the concentration of nitrogen in the surface soil of Curlew Valley. If an effect is to be seen, it will probably appear in soils which do not have a well established crust to help bind the soil and improve infiltration. Luxurious growth of higher plants such as crested wheatgrass provides the best guard against erosion and improvement of infiltration.

The per cm^2 loss of nitrogen from the surface soils of the Curlew Valley watershed may not be detectable in the soil since it is replaced by nitrogen fixation, but the amount of nitrogen moved to receiving basins in the runoff water may have an effect on the ecosystems there. Much of the runoff water from the southern part of Curlew Valley collects in low lying playa areas where it evaporates or infiltrates. Using Site 2 spring snow melt runoff as an example, the importance of these playas can be seen. Annually, the drainage from 1 ha of land like Site 2 would result in approximately 160,000 l of runoff from snow melt carrying approximately 400 g N to a receiving basin. A single sample of the surface soils of one of these playa areas in the area of Site 2 showed the concentration of nitrogen there to be nearly an order of magnitude lower (0.023%) than that of Site 2. Thus, much of the nitrogen gained by the playa must be lost, most probably by mechanisms described by Skujins and West (1973).

The fate of this nitrogen may be an important aspect of nitrogen dynamics in this ecosystem. This nitrogen affects the communities in receiving basins and receiving waters. Effort may be profitably spent studying the recycling of this nitrogen, and its impact on the ecosystem.

Nitrogen Fixation

Curlew Valley soil-algae crust nitrogen fixation can be expressed as a function of the population of nitrogen fixing organisms present, water availability, soil temperature and light energy. A model to accurately predict the amount of soil crust nitrogen fixation could be written given sufficient information about the relationship of each of these variables to the nitrogen fixation rate.

In order to make a "first cut" approximation of the amount of nitrogen fixation associated with the soil-algae crust, we have assumed that dark nitrogen fixation can be ignored and have constructed a simple model for Site 5 daylight nitrogen fixation. To do so we have first assumed that during daylight hours, light energy (intensity) is not limiting. The blue-green algae have been shown generally to be light saturated photosynthetically by rather low levels (approximately 400 ft-c) of illumination (Brown and Richardson, 1968). Rychert (1973) has found the nitrogen fixation optimum for Curlew Valley soil-algae crust to be between 2,000 and 10,000 lux (approximately 200 to 1000 ft-c). It is unlikely even on overcast days that the incident light on the crust surface would be below this range.

Eliminating light as a controlling factor in regulating nitrogen fixation we are left with nitrogen fixation as a function of soil water availability and surface soil temperature at any given site where the nitrogen fixing population is assumed to be uniform.

Laboratory studies of the effects of moisture on nitrogen fixation of Site 5 crusts yielded results previously shown in Figure 7. The relationship between soil moisture and nitrogen fixing activity can be expressed by the Michaelis-Menton equation.

$$V = \frac{Vmax \quad (M-C)}{(M-C) + Km} \tag{1}$$

Where V is the velocity or rate of the nitrogen fixation reaction. Vmax is the velocity of nitrogen fixation at which the function becomes zero order when all other regulating factors are constant; M is the percent surface soil moisture; C is the minimum percent soil moisture at which nitrogen fixation cannot be observed; Km is the percent surface soil moisture at which the nitrogen fixation rate is one-half of Vmax. For Site 5 crust, C=5.77% moisture by weight and Km=13.2% moisture.

The value of Vmax is dependent on the temperature. It would be very impractical if not impossible to empirically measure Vmax for any given temperature, and yet it is necessary to know the value of Vmax from actual data in order to construct a model which combines the effects of moisture and temperature on nitrogen fixation. To arrive at values for Vmax from actual data we can rearrange equation 1 so that we can solve for values of Vmax thus:

$$Vmax = \frac{V(M-C + Km)}{M - C} \tag{2}$$

By substituting known rates (V) at given temperatures and known moistures into equation 2, values of Vmax were obtained. Values of V from both field and laboratory experiments were used when both soil temperature and moisture were measured.

These values of Vmax were used to construct an Arrhenius plot (Figure 9). An "eye ball" fit of the data is shown as the dashed line parabola in the plot. This function is described by the equation.

$$\ln Vmax = -1043.66 + 605.98 \left(\frac{1000}{T}\right) - 87.62 \left(\frac{1000}{T}\right)^2 \tag{3}$$

Where T is temperature in degrees Kelvin, and Vmax is picomoles N_2 (C_2H_2) fixed cm^{-2} min^{-1}.

The assumption that the rate to temperature relationship was parabolic arose from observations made during the experiment on the response of the nitrogen fixation mechanisms to wetting at various temperatures. The behavior of the nitrogen fixing mechanism there was the same as that described by Dixon and Webb (1958) as being typical of enzyme systems denatured by temperatures above

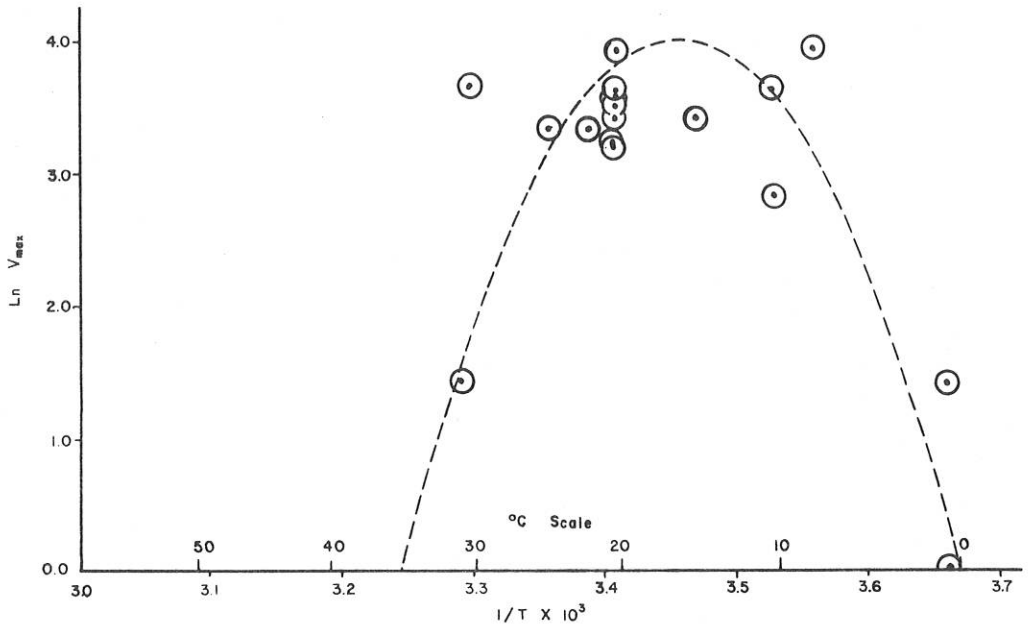

Figure 9. Hypothetical relationship of Vmax (N fixation rate) to temperature (Arrhenius plot).

an apparent optimum. As the temperature increases, the activity first increases then decreases as the denaturation rate of the enzyme or enzymes increases beyond the rate at which they are repaired.

By combining equations 1 and 3, a hypothetical model of daylight nitrogen fixation at Site 5 is constructed thus:

$$V = \exp\left[-1043.66 + 605.98\left(\frac{1000}{T}\right) - 87.62\left(\frac{1000}{T}\right)^2\right]\left[\frac{(M-C)}{(M-C)+Km}\right] \quad (4)$$

where $309\,K \geq T \geq 273K$ and $M \geq 5.77\,\%$ are constraints used to prevent negative values of V.

By applying this model (equation 4) to measured temperature, moisture and time data listed in Table 6, estimates of soil-algae crust daylight nitrogen fixation for Site 5 were obtained. The total of the various periods throughout the year indicates that 319 mg nitrogen may have been fixed per square meter at Site 5 during the daylight hours of the year shown. This is approximately 3 kg N/ha—yr, which is similar to Alexander's (1971) measurements in arid soils of Australia. Predicted rates for the weeks of October 1-7, 1972, and March 18-24, 1973 (Table 6) are very close to those measured by Mayland et al. (1966) (approximately 0.11 kg N/ha day), when the rate is assumed to continue over a 24-hr day.

Table 6. Estimation of nitrogen fixation at site 5, Sept. 10, 1972 to Sept 15, 1973.

Period	Estimated mean % Soil Moisture	Estimated mean Temp. (°K)	Minutes of light per Period	N-fixation Rate Pico mol/ $cm^2 \cdot min$	Nitrogen fixed $mgN_2/m^2 \cdot$ Period
Sept. 10-23, 1972	2.5	297	5586	0	0
Sept. 24-30, 1972	10.0	302	5446	2.07	3.16
Oct. 1-7, 1972	20.0	287	5320	27.39	40.79
Oct. 8-14, 1972	12.0	302	5194	2.54	3.98
Oct. 15-21, 1972	20.0	286	5075	25.55	36.30
Oct. 22-28, 1972	10.0	280	4942	4.40	6.09
Oct. 29-Nov. 4, 1972	5.0	283	4844	0	0
Nov. 5-11, 1972	10.0	279	4725	3.36	4.45
Nov. 12-18, 1972	20.0	282	4613	14.72	19.01
Nov. 19, 1972-Mar. 10, 1973	30.0	272	-	0	0
Mar. 11-17, 1973	30.0	273.5	5390	1.15	1.74
Mar. 18-24, 1973	22.0	286	5530	27.16	42.05
Mar. 25-31, 1973	9.0	285	5600	8.79	13.79
Apr. 1-7, 1973	7.0	282	5782	2.42	3.92
Apr. 8-14, 1973	3.0	295	-	0	0
Apr. 15-21, 1973	7.0	290	6034	4.75	8.02
Apr. 22-28, 1973	3.0	296	-	0	0
Apr. 29-May 12, 1973	2.0	305	-	0	0
May 13-19, 1973	5.0	301	-	0	0
May 20-June 2, 1973	7.0	301	13188	0.96	3.53
June 3-16, 1973	11.6	290	13398	17.06	64.00
June 17-July 7, 1973	7.0	294	13434	3.62	13.63
July 8-14, 1973	11.0	301	6650	3.18	5.92
July 15-21, 1973	7.0	304	6580	0.40	0.74
July 22-Sept. 1, 1973	1.0	311	-	0	0
Sept. 2-15, 1973	17.0	296	11550	14.84	47.99
				Years Total	319.11

It should be pointed out that predicted annual nitrogen fixation, for Site 5 at least, is insufficient to account for large changes in areal concentrations of standing crop nitrogen. A great deal of precision in sampling and analysis would be required to observe changes in surface soil nitrogen with season due to nitrogen fixation in the algal crust.

CONCLUSIONS

The following conclusions have been reached in the study:

1. Concentrations of surface soil total nitrogen in southern Curlew Valley are very uniform, and appear to be at steady state on an annual basis. Small seasonal increases and decreases in nitrogen content of the surface soil due to nitrogen fixation versus nitrogen removal processes may occur but are below the level of detection of methods employed in this study.
2. Net removal of nitrogen from the surface soils of Curlew Valley by precipitation-caused runoff water is insignificant on an annual basis.
3. Well established, highly lichenous soil algae crusts provide an aid to soil binding and water infiltration, and thereby inhibit the loss of soil nitrogen through runoff waters. Less structured and more poorly established soil-algae crusts are less protective and allow the loss of more nitrogen through erosion and leaching. Manipulation, such as plowing and planting to grasses, destroys the crust and allows for more erosive loss of nitrogen. However, heavy stands of ungrazed crested wheatgrass were the most effective inhibitor of runoff and erosion.
4. Consistently high concentrations of nitrate plus nitrite at Site 3 suggest that certain mechanisms of the nitrogen cycle, such as nitrification-denitrification, may be more important in some areas of the valley than at others.
5. Nitrogen fixation, as measured by the acetylene-ethylene assay, in Curlew Valley may vary considerably from one area to another, and from one soil-plant community to another.
6. Microscopal and visual characterization of soil surfaces apparently served as a reasonable estimator of nitrogen fixation potential and runoff potential. Well defined crusts and well established grass communities indicated lower runoff potential; high *Nostoc* and/or lichen populations indicated areas with high nitrogen fixing potential.
7. Nitrogen fixation in the sagebrush community immediately north of the IBP Desert Biome southern validation site probably does not exceed 10 kg/ N/ha/ yr. Nitrogen fixation predicted by a temperature-moisture dependent model was similar to that found by other workers in other arid environments.

FURTHER PUBLICATIONS

A report on carbon flux in algal crusts is currently being prepared for publication in 1975 as a companion study to this report.

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APPENDIX

Areal Concentrations of Surface Soil Total Nitrogen to a Depth of 1 cm in Curlew Valley

Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
Date	mgN/cm^2	Date	mgN/cm^2	Date	mgN/cm^2	Date	mgN/cm^2	Date	mgN/cm^2	Date	mgN/cm^2	Date	mgN/cm^2
7-15-72	1.57	7-15-72	2.77	7-15-72	1.43	8-14-72	1.40	9-15-72	2.87	9-08-72	1.95	9-08-72	3.13
7-21-72	2.47	7-28-72	2.06	7-21-72	2.31	8-18-72	1.75	9-27-72	2.88	9-15-72	2.26	9-15-72	1.87
7-28-72	2.20	8-11-72	2.64	7-28-72	2.76	8-25-72	1.59	9-30-72	3.75	9-22-72	2.50	9-22-72	2.70
8-11-72	1.61	8-18-72	2.41	8-11-72	2.73	9-01-72	1.77	10-07-72	2.09	9-30-72	2.90	9-30-72	2.23
8-14-72	2.20	8-25-72	2.11	8-14-72	2.0[illegible]	9-08-72	1.87	10-14-72	3.30	10-07-72	2.96	10-07-72	2.23
8-18-72	2.04	9-01-72	2.37	8-18-72	1.49	9-15-72	1.99	10-21-72	2.60	10-14-72	2.84	10-14-72	2.97
8-25-72	1.78	9-08-72	2.12	8-25-72	2.45	9-22-72	1.84	10-27-72	3.20	10-21-72	2.33	10-21-72	2.18
9-01-72	2.01	9-15-72	1.95	9-01-72	1.90	9-30-72	1.75	11-04-72	2.98	10-27-72	2.25	10-27-72	2.74
9-08-72	2.06	9-22-72	2.27	9-08-72	1.94	10-07-72	2.24	11-11-72	2.70	11-04-72	1.96	11-04-72	2.17
9-15-72	2.18	9-30-72	3.27	9-15-72	1.91	10-14-72	2.11	11-18-72	2.70	11-11-72	1.93	11-11-72	2.97
9-22-72	1.99	10-07-72	2.26	9-22-72	2.41	10-21-72	2.69	11-25-72	1.81	11-18-72	1.80	11-18-72	2.12
9-30-72	2.12	10-14-72	2.73	9-30-72	2.05	10-27-72	1.90	12-16-72	1.58	11-25-72	1.36	11-25-72	1.51
10-07-72	3.07	10-27-72	2.00	10-07-72	1.85	11-04-72	1.60	12-30-72	1.20	12-16-72	1.69	12-16-72	2.32
10-14-72	2.07	11-04-72	2.04	10-14-72	2.23	11-11-72	1.54	1-13-73	2.40	12-30-72	0.76	12-30-72	0.84
10-21-72	1.67	11-11-72	2.00	10-21-72	1.69	11-18-72	1.44	1-27-73	1.35	1-13-73	1.39	1-13-73	1.94
10-27-72	2.08	11-18-72	1.85	10-27-72	2.41	11-25-72	1.03	2-10-73	1.99	1-27-73	1.01	1-27-73	0.92
11-04-72	1.66	11-25-72	2.34	11-04-72	1.70	12-16-72	2.01	2-24-73	2.32	2-10-73	1.76	2-10-73	2.41
11-11-72	1.51	12-16-72	1.51	11-11-72	1.39	12-30-72	0.69	3-27-73	2.69	2-24-73	2.80	2-24-73	1.69
11-18-72	1.27	12-30-72	1.37	11-18-72	1.65	1-13-73	1.63	4-07-73	1.99	3-23-73	1.72	3-23-73	1.77
11-25-72	1.81	1-27-73	0.82	11-25-72	1.79	1-27-73	1.72	4-13-73	2.43	4-07-73	1.62	4-07-73	1.91
12-16-72	1.69	2-10-73	1.84	12-16-72	0.91	3-17-73	1.76	4-21-73	2.33	4-21-73	2.11	4-13-73	2.03
12-30-72	1.90	2-24-73	1.12	12-30-72	0.69	4-07-73	1.38	4-28-73	2.63	4-28-73	1.91	4-21-73	2.79
1-13-73	1.93	4-07-73	2.48	1-13-73	1.54	4-13-73	1.31	5-03-73	2.05	5-03-73	1.98	4-28-73	1.93
1-27-73	1.39	4-13-73	2.34	1-27-73	1.50	4-21-73	2.51	5-12-73	2.68	5-12-73	2.17	5-03-73	2.09
2-10-73	1.36	4-21-73	2.09	2-10-73	1.45	4-28-73	1.73	5-19-73	3.23	5-19-73	2.50	5-12-73	2.25
2-24-73	1.24	4-28-73	2.71	2-24-73	0.84	5-03-73	1.41	6-02-73	2.65	6-02-73	2.69	5-19-73	3.76
3-31-73	1.26	5-03-73	1.52	3-31-73	0.20	5-12-73	1.96	6-20-73	2.60	6-20-73	1.57	6-02-73	2.14
4-07-73	1.32	5-12-73	2.06	4-07-73	1.58	5-19-73	2.33	7-13-73	1.78	7-13-73	1.88	6-20-73	1.99
4-13-73	1.15	5-19-73	1.96	4-13-73	1.27	6-02-73	1.94	7-20-73	1.95	7-20-73	1.84	7-13-73	1.97
4-21-73	1.67	6-02-73	1.86	4-21-73	1.44	6-20-73	1.39	8-11-73	2.38	8-11-73	1.87	7-20-73	2.12
4-28-73	1.77	6-20-73	1.74	4-28-73	1.36	7-20-73	1.62	9-10-73	2.12	9-10-73	1.90	8-11-73	1.74
5-03-73	1.91	7-13-73	1.16	5-03-73	1.63	8-11-73	1.71	9-27-73	2.43	9-27-73	1.99	9-10-73	1.88
5-12-73	1.51	7-20-73	1.39	5-12-73	2.25	9-10-73	1.91	Runoff Plot		Runoff Plot		9-27-73	2.31
5-19-73	2.29	8-11-73	2.81	5-19-73	1.33	9-27-73	1.43	9-27-73	1.56	9-27-73	1.98	Runoff Plot	
6-02-73	1.25	9-10-73	1.60	6-02-73	1.50	Runoff Plot						9-27-73	2.05
6-15-73	1.24	9-27-73	1.82	6-15-73	1.34	9-27-73	1.51						
6-20-73	1.38	Runoff	Plot	6-20-73	1.76								
7-20-73	1.44	9-27-73	1.66	7-13-73	1.51								
8-11-73	1.14			7-20-73	1.28								
9-10-73	1.26			8-11-73	1.40								
9-27-73	1.39			9-10-73	1.02								
Runoff Plot				9-27-73	1.45								
9-27-73	1.35			Runoff Plot									
				9-27-73	2.07								

Method of calculation of areal concentrations of standing crop total nitrogen.

$$mgN/cm^2 = \frac{\%N}{100 \times \frac{5\ cores}{sample} \times \frac{1.89 cm^2}{core}} \times mg\ sample$$

in which $\%N = \frac{mgN}{mg\ subsample} \times 100$