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Carbon, Nitrogen and Algal Biomass in Cold Desert Soil Crusts

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CARBON, NITROGEN AND ALGAL BIOMASS IN COLD DESERT SOIL CRUSTS

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

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Mary C. Vogelsberg

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ABSTRACT

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in Cold Desert Soil Crusts

by

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The algal biomass, total organic carbon, total nitrogen and percent soil moisture of soil crusts for a ten month period are presented for the Curlew Valley region of northern Utah. The estimates establish a significant relationship among these parameters.

A method involving chlorophyll extraction to determine the biomass of soil algae has been developed, and from this method the following conclusions are suggested: the revegetation of soil surfaces by algal crusts after lethal treatment, without physical disruption, appears to be rapid; there is no apparent relationship between the amount of algal biomass and the type of vascular vegetation present.

(54 pages)

INTRODUCTION

Tightly knit trichomes of filamentous algae and fungal hyphae form the basis for the soil crusts which are extensively visible on the soil surface of Curlew Valley in the Utah-Idaho cold desert.

The existence of this crust affects the soil surface in a number of ways. It precedes the development of higher plants and acts as a barrier to soil erosion in interspacial areas between vascular vegetation. The soil crust is also a source of surface organic material. Algal genera of known nitrogen-fixing ability are present in soil surface samples taken from Curlew Valley and such crusts contribute both nitrogen and carbon to desert soil systems (Lynn and Cameron, 1971).

Due to the present lack of knowledge regarding the role of desert soil algae, this investigation was undertaken.

REVIEW OF LITERATURE

Soil crust characteristics

Although there is abundant soil surface cover by lichens (*Collema tenax*, *Dermatocarpon lachenum*, *Fulgensia fulgens*) and both free-living and associated blue-green algae (*Nostoc sp.* and *Microcoleus sp.*) in the southern section of Curlew Valley (Lynn and Cameron, 1972), there is relatively little information available regarding the role of algae in desert soils particularly in regard to their contribution to the soil nitrogen and carbon content (Cameron and Blank, 1966).

The distribution of some desert soil crusts is mainly dependent on the mean annual rainfall and mean maximum summer temperature, and where established, the soil crust growth is restricted to the surface one centimeter of soil (Cameron,1964). The establishment of these crusts is precursory to the development of mosses and vascular plants (Booth, 1941; Lynn and Brock, 1969).

The soil algae of arid zones display tenacity in their survival. Many species of blue-green desert soil algae, including *Nostoc sp.* and *Scytonema sp.* have been demonstrated to survive four to five years of exposure to continuous vacuum (Cameron, Morelli, and Conrow, 1970). Desert soil algae can respond rapidly, in both growth and metabolism, to available moisture provided by either light rainfall or temporary melting or surface snow and ice cover (Fuller, Cameron, and Raica, 1960). They also have been shown to maintain an active physiology at temperatures as low as -30 C (James, 1955; Koob, 1968), but fluctuating low

temperatures, such as prevail during late fall and early spring, can injure these soil crust components (Campbell, Biederbeck, and Warder, 1971).

Soil crust contributions

The importance of desert soil crusts has been shown in colonizing areas devoid of plant life has been previously documented (Cameron and Blank, 1966). Once established, soil crusts protect the soil surface by retarding evaporation, preventing wind erosion and preventing water erosion by breaking the force of raindrops (Booth, 1941).

These crusts also affect the properties of the soil on which they establish. The microflora can affect soil aggregation and increase soil tensile strength (Bond, 1964; Fletcher and Martin, 1948). Although soil crusts seem to have little direct effect on the pH of the soil (Loope and Gifford, 1972), they do serve as an important source of organic matter (Fletcher and Martin, 1948; Lund, 1962; Shields and Durrell, 1964). Soil algae have been shown to grow autotrophically while contributing appreciably to the combined carbon and nitrogen status of Arizona soils (Cameron and Fuller, 1960). In Curlew Valley soils, the soil crusts have been shown to practice vigorous carbon and nitrogen fixation during periods of moisture (Skujins, 1971).

Nitrogen fixation by soil crusts

The ability to fix atmospheric nitrogen has been shown in some desert soil crusts (Cameron and Fuller, 1960; Mayland, McIntosh, and Fuller, 1966). Most of the gelatinous lichen group, which includes

Dermatocarpon lachenum and *Fulgensiz fulgens*, are known nitrogen-fixing organisms and the algal symbiont of *Collema tenax* is *Nostoc sp.*, a blue-green alga with known nitrogen-fixing abilities (Henriksson, 1951; Scott, 1956). Granhall (1970) has shown the general nitrogen-fixing capacity of isolated soil algae to be approximately the same for all the species of algae he encountered.

The level of nitrogen in soil crusts is four to five times as high as the soil below them (Fuller, Cameron, and Raica, 1960). This high level could reflect nitrogen fixation by both blue-green algae and bacteria, since inoculation of soil with blue-green algae has been shown to increase the development of nitrogen-fixing bacteria (Shtina et al., 1968). This nitrogen has been proven to be subsequently available to higher plants by the use of labeled nitrogen (Mayland, McIntosh, and Fuller, 1966). Soil crusts with small populations of nitrogen-fixing blue-green algae and bacteria produce an annual rate of 0-3 kg N/ha estimated by the acetylene reduction method (Line and Loutit, 1973).

Nitrogen fixation by soil crusts is affected by physical conditions of the environment although neither light nor temperature variations between 9-35 C greatly influences the rate of nitrogen fixation in the temperate regions (Henriksson, 1971). In soil crusts from Curlew Valley, nitrogen fixation occurs optimally at 30 C and is greatly reduced below 20% soil moisture (Skujins, 1971). This reduction in nitrogen fixation during low soil moisture periods could be due to the necessity of high soil moisture for nitrogen fixation in blue-green algae (Shtina et al., 1968). However three hours after a moisture event in the desert, it has

been determined by the acetylene reduction method that, the soil crust produces 0.7 μg $N/cm^2/hr$, and by using this figure it is possible to estimate that the desert soil crust produces 3-4 g of N/ha/hr following a rainfall event (MacGregor and Johnson, 1971).

Knowledge of desert soil crusts is increasing in importance with the increasing development of arid lands due to the growth in world population and expectations. This knowledge is necessary in characterizing and developing the fertility and productivity of desert soils (Cameron, 1971); also the role of desert soils in serving as a major natural sink for carbon monoxide released into the atmosphere must be understood (Inman, Ingersoll, and Levy, 1971).

PROCEDURE

Test sites

Four fenced, nine square meter test sites were established in southern Curlew Valley on the basis of the dominant vascular vegetation of the area (Figure 1). The two sagebrush (*Artemisia tridentata*, Nutt.) and the greasewood (*Sarcobatus vermiculatus*, Hook) sites were in areas of indigenous vegetation; the crested wheat (*Agropyron cristatum*) site was in an area of introduced forage grass.

The four test sites were treated with Dowfume MC-2 (Methyl Bromide) to kill the vascular vegetation and most of the viable microbes in the surface 5 cm of soil. The area adjacent to the test site was established as the control area. Before gassing the sites with Dowfume MC-2, soil and crust samples were taken from the sites and adjacent control areas to establish that the microbe population of the site, before kill, was representative of the general microbial population of that area. The perimeter of the plot was trenched and a plastic sheet placed over the site with its edges buried in the trench to produce a seal. The gas was then applied as a mist via tubing leading from aerosol cans. After six hours the plastic sheet was removed and after kill soil and crust samples taken to determine the extent of the microbial kill.

Determination of the effect of the test site treatment

One gram of each soil sample (taken to determine the extent of the kill) was suspended in 10 ml of sterile distilled water and 0.1 ml of

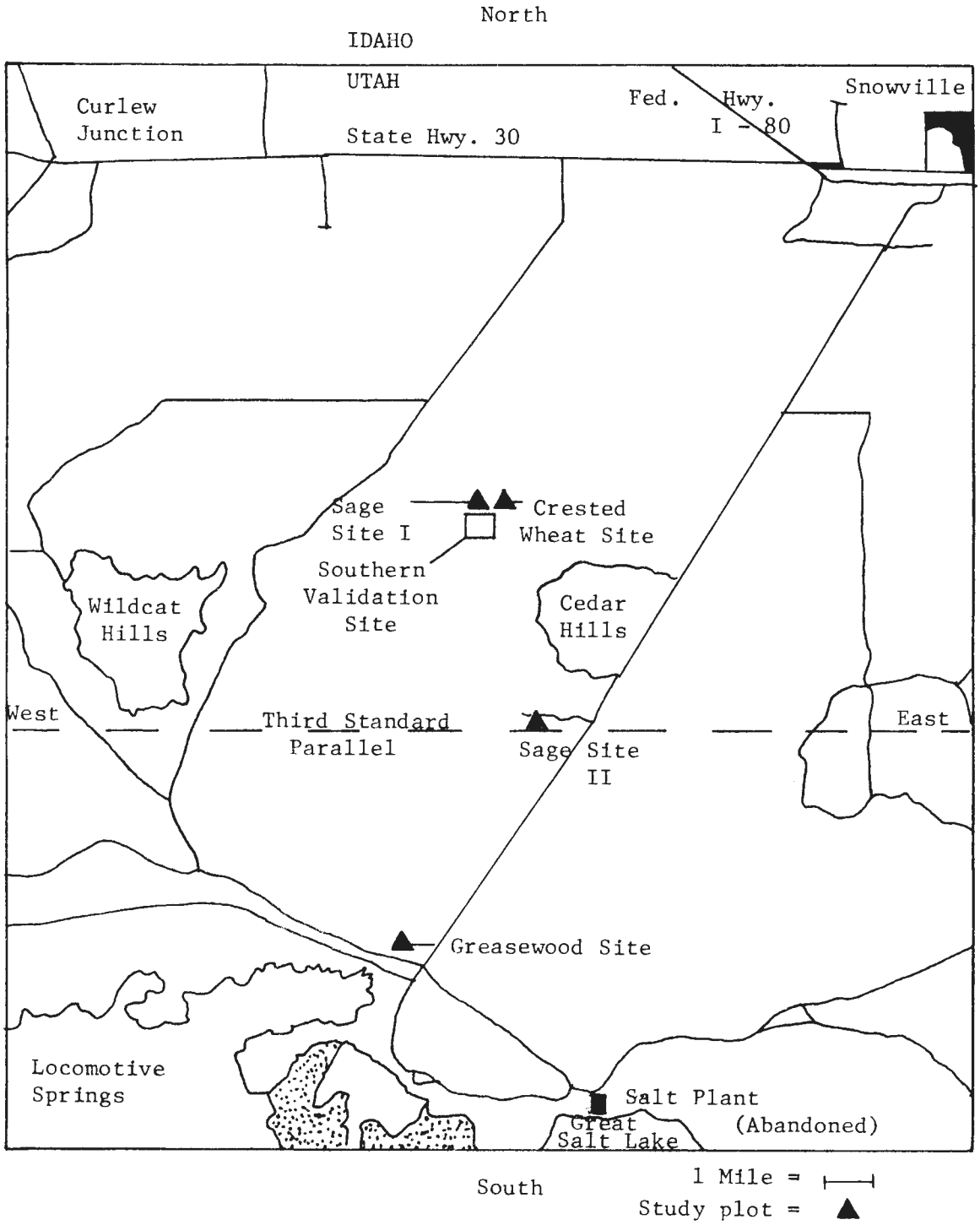


Figure 1. Map locating study plots.

the resulting suspension was used as inoculum which was spread on plates of Burk's nitrogen-free ion agar media (Burk and Lineweaver, 1930; see Appendix) and *Euglena* agar media (Starr, 1964, see Appendix). The inoculated plates of *Euglena* media were incubated for 48 hours under constant florescent light of 400 ft.c. intensity at 24 ± 2 C. The inoculated plates of Burk's nitrogen-free ion agar media were incubated under the same conditions for 1 week. At the end of the incubation period, the agar plates were counted for the bacterial colonies present using a Quebec Colony counter.

Another one gram subsample of each soil sample was suspended in 10 ml of *Bristol's* medium (Starr, 1964; see Appendix). This suspension was used for a series dilution to a dilution of 10^{-6} and then incubated under the same conditions as described above for a three week period. At the end of the incubation, the suspensions were examined for the presence of green algal material.

The bacterial and algal populations at the test sites were again estimated by the same techniques 10 monthes after the kill to determine the amount of recovery attained.

Sampling

Samples were removed from the interspacial areas between vascular plants of both the test sites and adjacent control areas on a regular basis using a cork borer of 1.5 cm diameter. Five cores of 1 cm depth were placed in individual sterile plastic bags (Whirlpaks) for each sample. The five cores thus represented a surface area of 0.00088 M^2. This sampling process was repeated in 3 distinct areas of both the test

site and adjacent control, which provided 3 treated and 3 control replicates for each analysis. After returning to the lab, these samples were dried and homogenized before analyses to determine algal biomass, total organic carbon, and total nitrogen. Bacterial analyses were performed on undried samples.

Determination of soil moisture

Soil moisture was measured in the field at the time of sampling at each site. The percent by weight of soil moisture was determined for the soil depths of 0-1 cm, 2-3 cm, and 4-5 cm using the carbide-acetylene method (Parks Speedy Moisture apparatus). A soil sample of known weight was mixed with a known weight of calcium carbide inside the apparatus. The pressure of the gas generated by the reaction of the calcium carbide with the moisture of the soil sample registered as percent by weight of soil moisture on the pressure gauge of the apparatus.

Determination of algal biomass

This method was adapted from the method to determine chlorophyll A in the presence of pheophytin (American Public Health Association, 1971). The chlorophyll in each sample was extracted in 100 ml of 90% acetone for 48 hours in the dark on a Lab-line orbital shaker at 80 rotations per minute. The chlorophyll solution was then filtered through glass fiber filters to remove particulates. The optical density of the solution was then read in a one-half inch cell on a Bausch and Lomb Spectronic 20 spectrophotometer at 665 mμ and 750 mμ both before

and after acidification with 1 drop of concentrated hydrochloric acid. These readings were then applied in the following equations:

$$\text{Chlorophyll A } \frac{\text{mg}}{\text{m}^2} = \frac{26.73\left[(665_b - 750_b) - (665_a - 750_a)\right] \times V}{A}$$

$$\text{Pheophytin A } \frac{\text{mg}}{\text{m}^2} = \frac{26.73\ (\ [1.7]\ [665_a] - 665_b)\ \times V}{A}$$

$$\text{Algal biomass } \frac{\text{kg}}{\text{ha}} = \text{chlorophyll A mg/m}^2 \times 3.15$$

665_a = optical density reading at 665mμ after acidification

665_b = optical density reading at 665mμ before acidification

750_a = optical density reading at 750mμ after acidification

750_b = optical density reading at 750mμ before acidification

V = volume in liters of extracting solution

A = area of the sample

The conversion factor for chlorophyll A to algal biomass was taken from previous work completed in this laboratory (Lynn, 1971; Lynn and Cameron, 1972). Soil crusts were cultured to establish crusts of uniform algal composition, without the usual associated fungus and detritus. Comparable samples from these crusts were taken in increasingly larger sizes to determine if a linear relationship existed between algal biomass and chlorophyll A content. The algal biomass of one sample was established by ashing the sample, while the chlorophyll A of the comparable sample was extracted using the previously described extraction

technique. By comparison of these analyses it was found that there was a linear relationship in which algal biomass was related to the chlorophyll A content of the sample when multiplied by a conversion factor of 3.15.

Since ashing samples to determine their biomass did not differentiate between living and dead material; the chlorophyll A method was a more accurate predictor of the algal biomass alone, due to the presence of biomass in the form of fungus and detritus in natural soil crusts. In addition, the pheophytin content served as a measure of the physiological condition of the algae present.

Determination of total organic carbon

The total organic carbon content of the samples was determined by the dichromate technique of Walkley and Black (1934). First, the total weight in grams of the sample was determined and then a one gram subsample was placed in a 500 ml flask. After addition of 10 ml of 1 N potassium dichromate, 20 ml of concentrated sulfuric acid was added. This mixture was then allowed to stand for 30 minutes. This solution was diluted to 200 ml with distilled water and 6 drops of ferroin indicator added. The resulting solution was titrated with 1 N ferric sulfate. The 1 N ferric sulfate was standardized daily. Theoretically, each ml of potassium dichromate reduced is equal to 3 mg of organic carbon in the sample. The amount of total organic carbon in mg/g of soil was calculated from the above data as follows:

$$\text{Total Organic Carbon/kg C/ha} = \frac{\text{ml of titrant used} \times 3 \times \text{total weight of subsample in grams} \times 10^{-2}}{0.00088\ M^2}$$

The estimates of total organic carbon attained by the method above are normally around 10 percent below the actual level of total organic carbon in the sample (Porcella et al., 1973); this 10 percent decrease is reflected in the data contained herein.

Determination of total nitrogen

The total nitrogen content of the samples was determined at the Utah Water Research Lab using a Coleman Model 29 nitrogen analyzer (Coleman Instruments, 1968). This analysis yielded the percentage of nitrogen present in the samples which was used in the following formula:

$$\text{Total Nitrogen kg N/ha} = \frac{\text{percent N} \times \text{total weight of sample in grams} \times 10^{-2}}{0.00088\ M^2}$$

Determination of percent soil surface cover by algal crusts and average algal biomass present

Randomly placed transects of 100 meters were established in each area of differing vascular vegetation as determined by Holte and Adamson (1971) in both the southern sagebrush and southern crested wheat validation sites (Figures 2 and 3). At intervals of 1 meter the presence or absence of algal crust was visually determined and recorded. The number of readings showing presence of algal crust of the 100 readings taken for each transect were then stated as the percentage of soil surface cover by algal crust.

Utilizing the same transect, one core was taken at intervals of 5 meters. A composite sample of the 20 cores taken from each transect was analyzed for algal biomass as previously described.

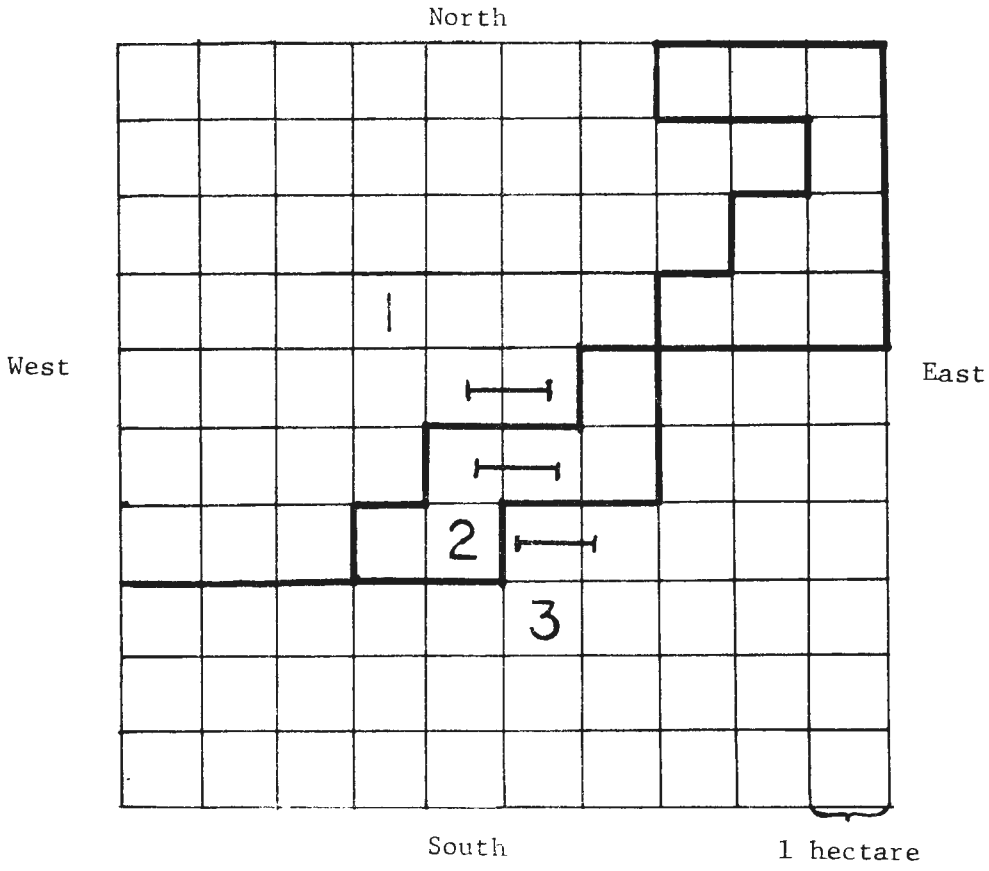
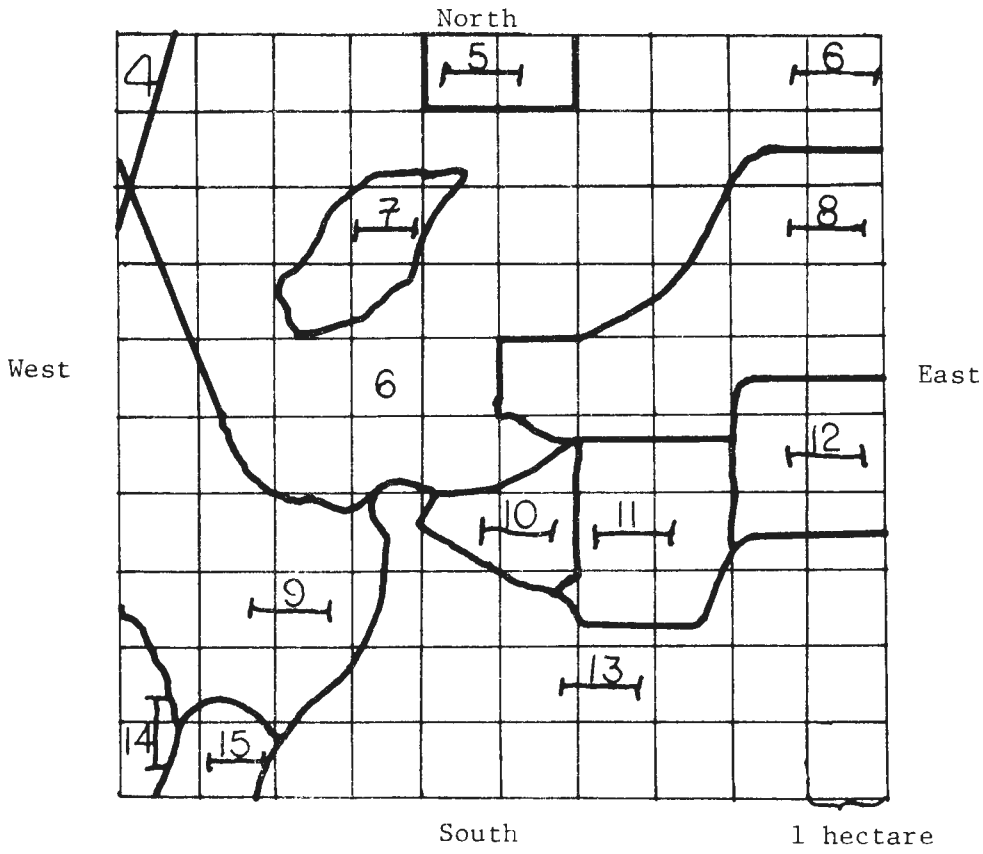


Figure 2. Transect locations in southern grass area.



= Transect location

= Vegetation zone number

Figure 3. Transect locations in southern sage area.

RESULTS AND DISCUSSION

Effect of test site treatment

The approximately 100 percent kill of the bacteria at the test sites demonstrated the effective nature of the methyl bromide (Table 1). *Euglena* medium was chosen to estimate the heterotropic bacterial populations, while the Burk's nitrogen-free medium estimated the nitrogen-fixing bacterial populations. The slight decrease in the percentage kill for the sagebrush II and crested wheat sites are thought to be due to a slight increase in soil moisture during the treatment of those sites.

Comparison of the before-kill and control estimates for July, 1972, suggested that the test site bacterial population was representative of the control bacterial population. Also, a comparison of the two control estimates for July, 1972 and May, 1973, suggested that the organisms had recovered from the treatment over the 10 month period.

The algal population at each test site was reduced with the methyl bromide treatment from at least five algal cells per gram of soil to at least 1 algal cell per gram of soil. Comparison of the algal populations at the killed and control sites after the ten month recovery period resulted in both populations showing at least six algal cells per gram of soil.

Survey of percentage soil surface cover and biomass of soil algae

After comparison of the estimations of percent algal cover with the experimentally determined biomass of the soil algae for the areas

Table 1. Effect of methyl bromide treatment on bacterial populations

Media used	Sample	Date	Average total number of bacterial colonies/gram of soil			
			Sagebrush I	Greasewood	Sagebrush II	Crested wheat
Euglena Agar	Before kill	July 1972	152×10^5	126×10^5	45×10^5	39×10^5
	After kill	July 1972	171	540	203,000	67,300
		May 1973	157×10^5	134×10^5	60×10^5	44×10^5
	Control	July 1972	149×10^5	106×10^5	51×10^5	49×10^5
		May 1973	146×10^5	162×10^5	61×10^5	39×10^5
	% kill	July 1972	~100%	~100%	93%	98%
Burk's N-free Agar	Before kill	July 1972	71×10^5	32×10^5	40×10^5	51×10^5
	After kill	July 1972	329	2,400	7,500	94,000
		May 1973	67×10^5	37×10^5	45×10^5	51×10^5
	Control	July 1972	26×10^5	29×10^5	41×10^5	48×10^5
		May 1973	75×10^5	32×10^5	51×10^5	54×10^5
	% kill	July 1972	~100%	99%	98%	98%

of differing vascular vegetation, there was no apparent relationship between the type of vascular vegetation and the algal cover or biomass of soil algae present (Table 2). The percent algal cover was not always proportional to the algal biomass as measured. Since the cover data was acquired visually and the biomass data analytically, it appeared that much of the algal biomass was not easily seen on the soil surface. The visible soil crust was composed of algae associated with fungal hyphae, while free-living soil algae, though present, were not as obvious. Therefore, the free-living soil algae apparently constituted the difference between the visually estimated cover and biomass results. The southern grass validation site, which was the most recently disturbed area of those surveyed, showed the most consistent algal cover and algal biomass present. This probably was a result of the more general homogeneity of the soil caused by plowing and uniform seeding, and also a common origin time; since length of establishment seemed to have a greater effect on algal biomass than the dominant vascular vegetation present.

Monitoring control sites

Comparison of the 4 control areas with regard to algal biomass, determination of total organic carbon and total nitrogen indicated a seasonal fluctuation in algal biomass and related changes in soil nitrogen and carbon.

The trend, in Figure 4, of algal biomass during the summer appeared unstable, probably due to differences in the precipitation at each area. During September algal biomass began to increase, apparently due to the increased moisture received from morning frosts. After the snow cover

Table 2. Transect results

Zone number	Vegetation type	Percent algal soil surface cover	Algal biomass Kg/ha
Southern grass validation site			
1	*Agropyron cristatum* *Atriplex confertifolia* *Sitanion hystrix*	80	96
2	*Agropyron cristatum* *Atriplex confertifolia*	80	96
3	*Agropyron cristatum*	80	96
Southern sage validation site			
5	*Artemisia tridentata* *Atriplex confertifolia* *Chrysothamnus vascidiflorus* *Sitanion hystrix*	82	144
6	*Artemisia tridentata* *Sitanion hystrix* *Atriplex confertifolia*	74	144
7	*Atriplex confertifolia* *Sitanion hystrix*	61	193
8	*Artemisia tridentata* *Atriplex confertifolia* *Chrysothamnus vascidiflorus* *Sitanion hystrix*	73	191
9	*Artemisia tridentata* (dead) *Sitanion hystrix*	73	96
10	*Artemisia tridentata* *Atriplex confertifolia*	78	169
11	*Artemisia tridentata* *Atriplex confertifolia* *Chrysothamnus vascidiflorus*	78	217
12	*Artemisia tridentata* *Elymus cinereus*	80	167
13	*Artemisia tridentata* (dead) *Halogeton glomerata*	41	96
14	*Artemisia tridentata* *Sitanion hystrix*	67	96
15	*Sitanion hystrix*	70	239

Table 2. Continued

Zone number	Vegetation type	Percent algal soil surface cover	Algal biomass Kg/ha
Sample sites			
	Sagebrush I	84	67
	Greasewood	70	56
	Sagebrush II	87	52
	Crested wheat	73	125

was initially established, the algal biomass remained at a steady, high level with adequate moisture provided by the snow. By the end of January, the algal biomass had begun a decline which lasted throughout February. During this period the ground remained frozen, without the slight thaw at the soil-snow interface. This allowed enough moisture for algal activity during the earlier winter months. With the increased temperature and solar radiation in March, this thawing resumed allowing the algal biomass to increase while the snow cover remained. During April and May the snow cover was lost as a constant moisture source, and the algal biomass began to again fluctuate with moisture events.

The level of pheophytin A was established as part of the test for algal biomass (Figure 5). Since pheophytin A is a physiologically inactive degraded form of chlorophyll A, it was used to indicate the physiological condition of the algae (American Public Health Association, 1971). The highest levels of pheophytin A were reached during the summer months, with the prolonged periods of low soil moisture resulting in

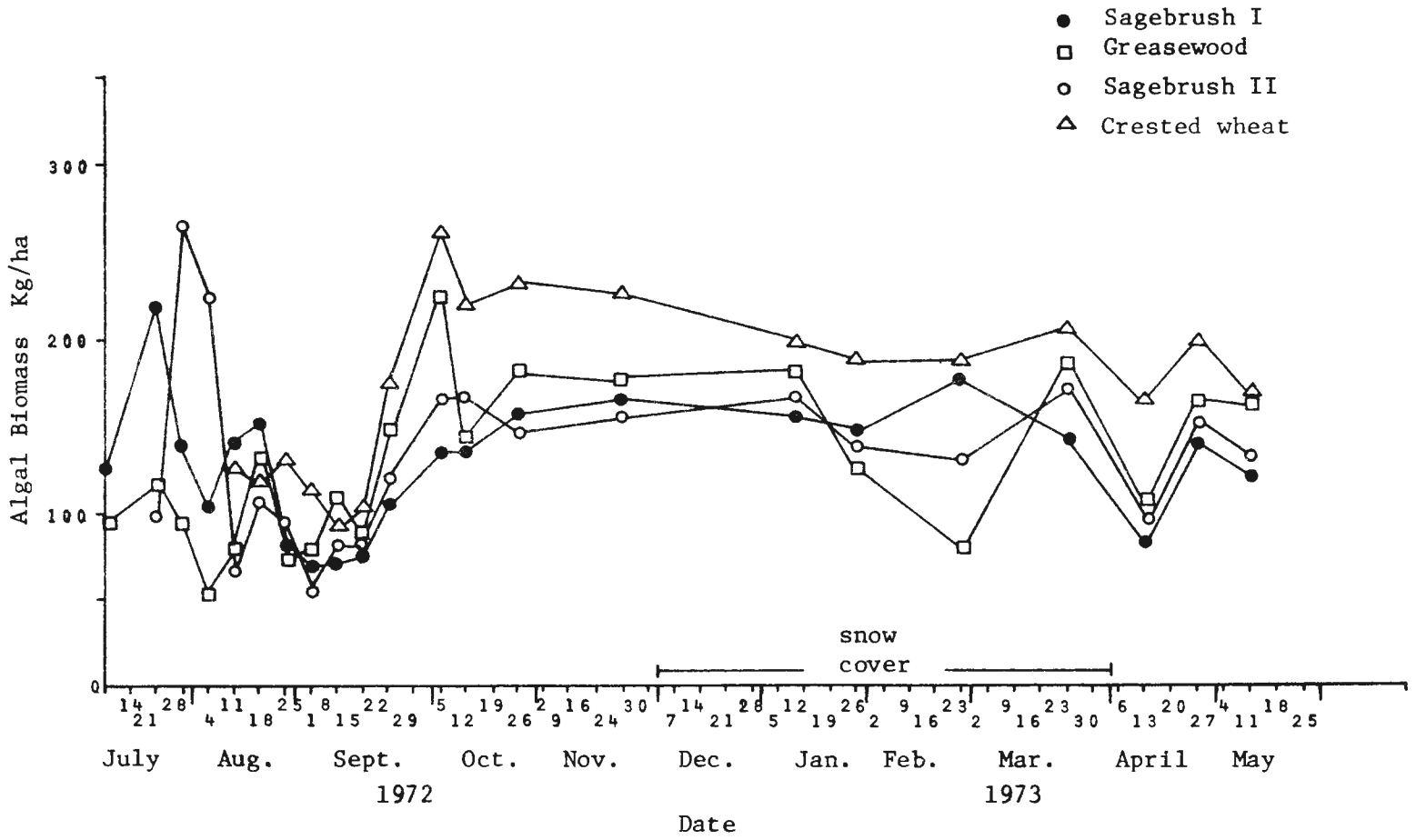


Figure 4. Algal biomass (Kg/ha) for untreated sites.

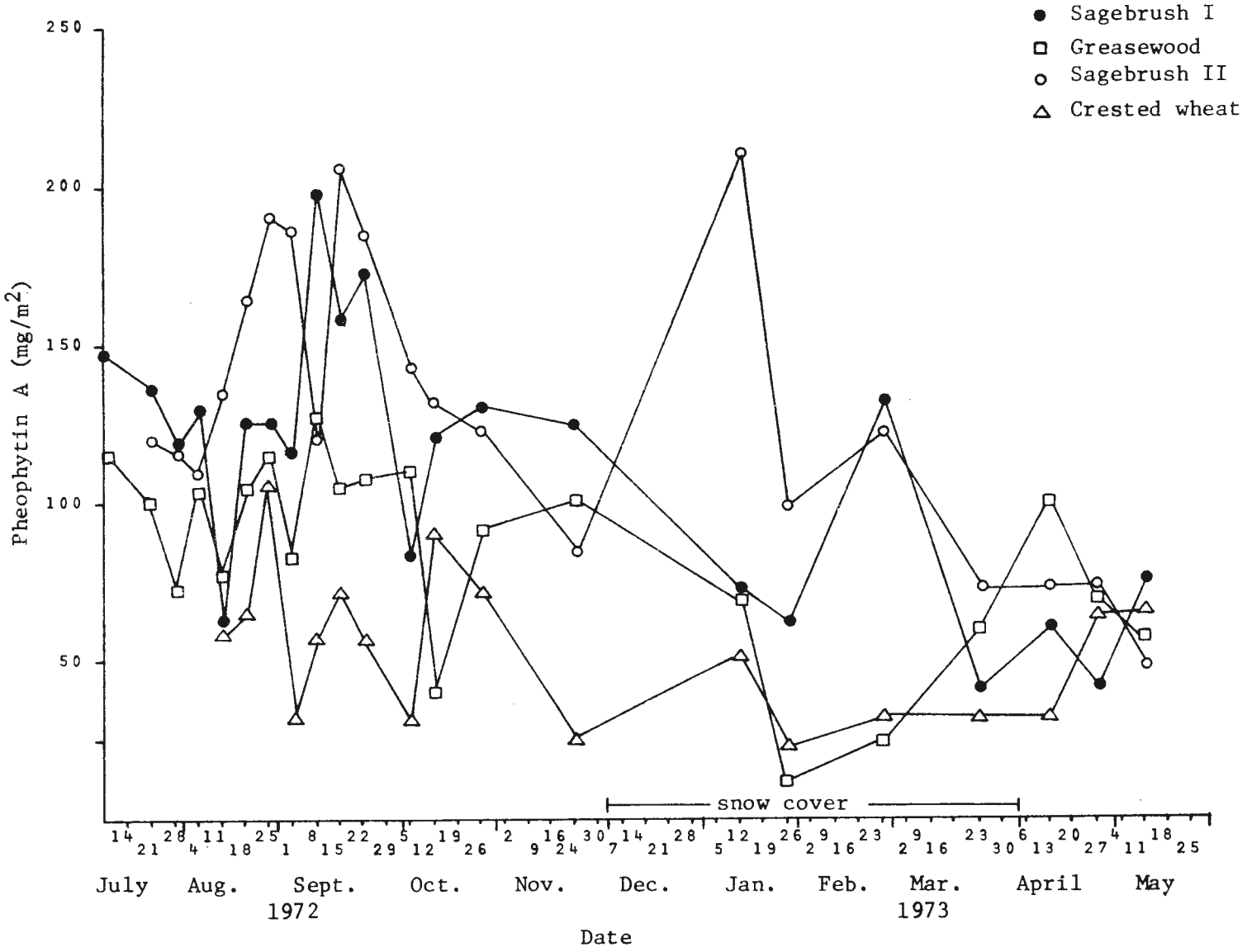


Figure 5. Pheophytin A (mg/m^2) for untreated sites.

algal death. The next highest levels of pheophytin A occurs during the late winter months, while the ground was frozen. The fall and spring provided the lowest pheophytin A readings, indicating that the least chlorophyll A degradation occurred during these periods. The lowest levels of pheophytin A were detected in the youngest areas of greasewood and crested wheat, which suggested the soil crust was still actively growing. The highest levels of pheophytin A were detected in the two sagebrush areas which had been established for the longest time. This observation suggested that these soil crusts were no longer expanding and were presumably at steady state.

The levels of total organic carbon (Figure 6) and total nitrogen (Figure 7) appeared to decrease from the summer to the winter. The control sites did not appear to maintain a distinct level in relation to each other. The inconsistencies of both of these parameters seemed to emphasize the heterogeneity of the soil crusts and the effects of diverse moisture conditions.

Monitoring test sites

Comparisons within sites between killed and control levels (Figures 8, 9, 10 and 11) exhibited little difference between the two. This suggested that the soil algae within the treatment sites were able to invade and reproduce after the first rainfall event following the lethal treatment. This apparently occurred at a rapid enough rate to counteract the decomposition that would have made the treatment effects visible. Summer thunderstorm activity provided precipitation events at all of the sites studied.

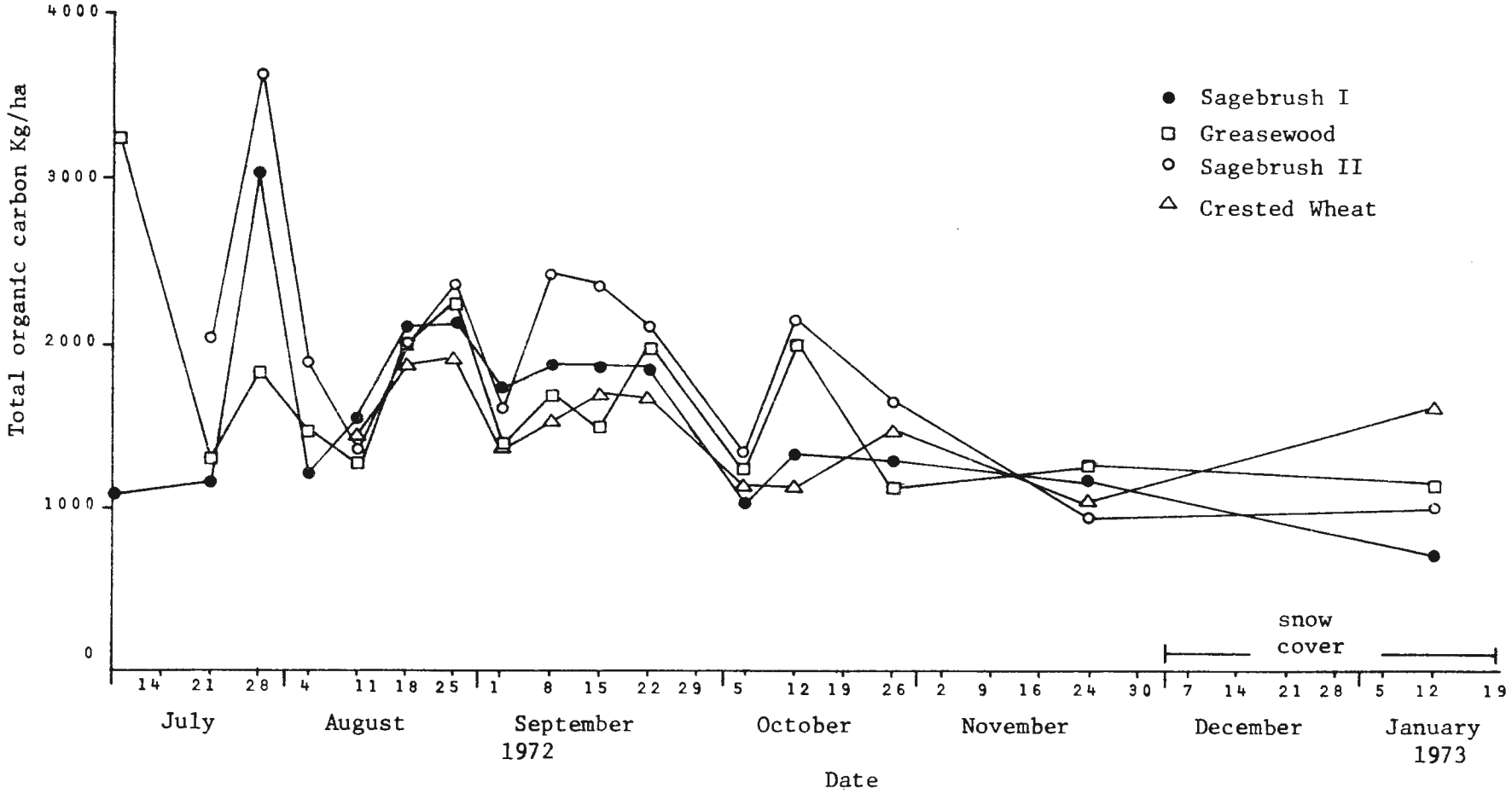


Figure 6. Total organic carbon (Kg/ha) for untreated sites.

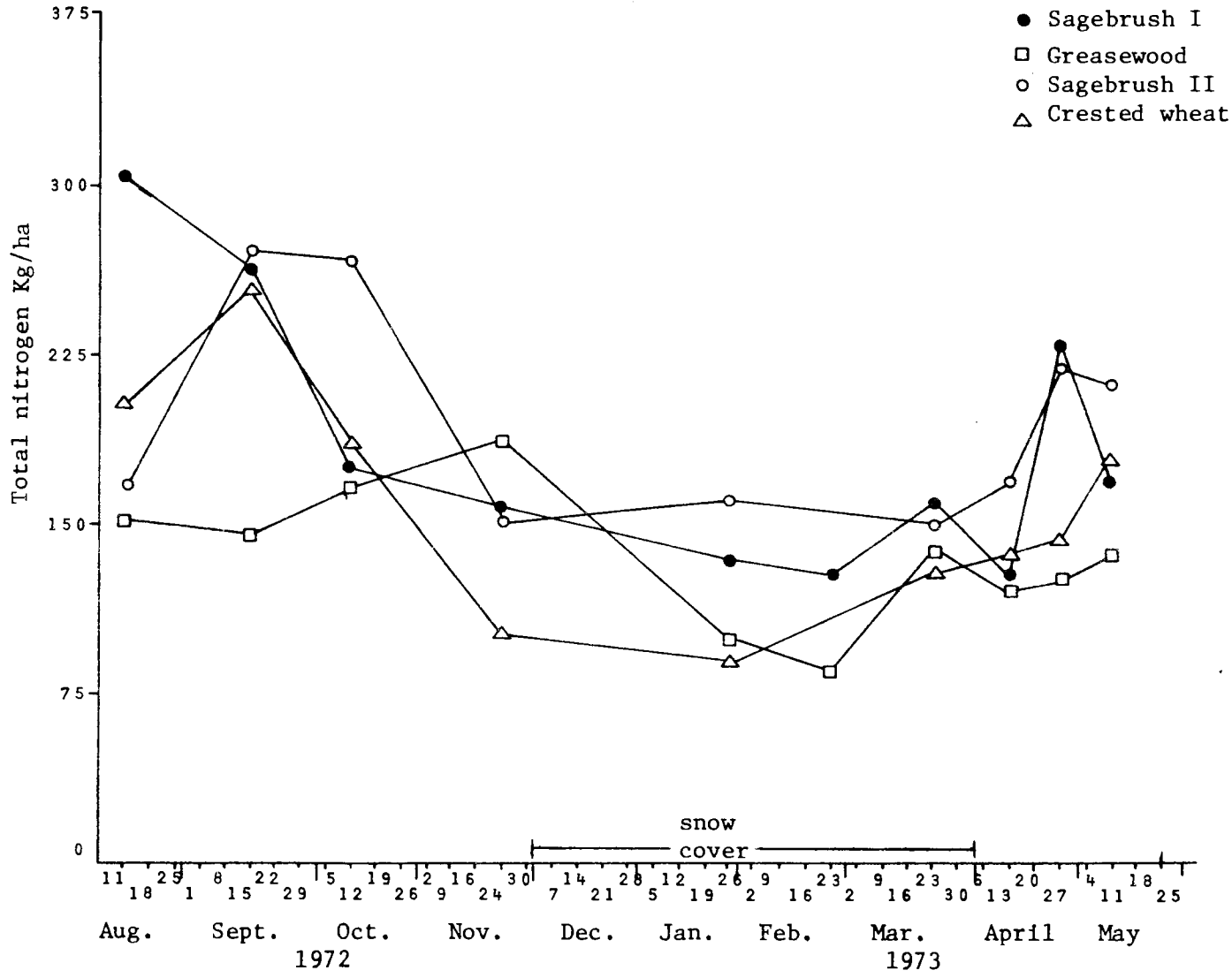


Figure 7. Total nitrogen (Kg/ha) for untreated sites.

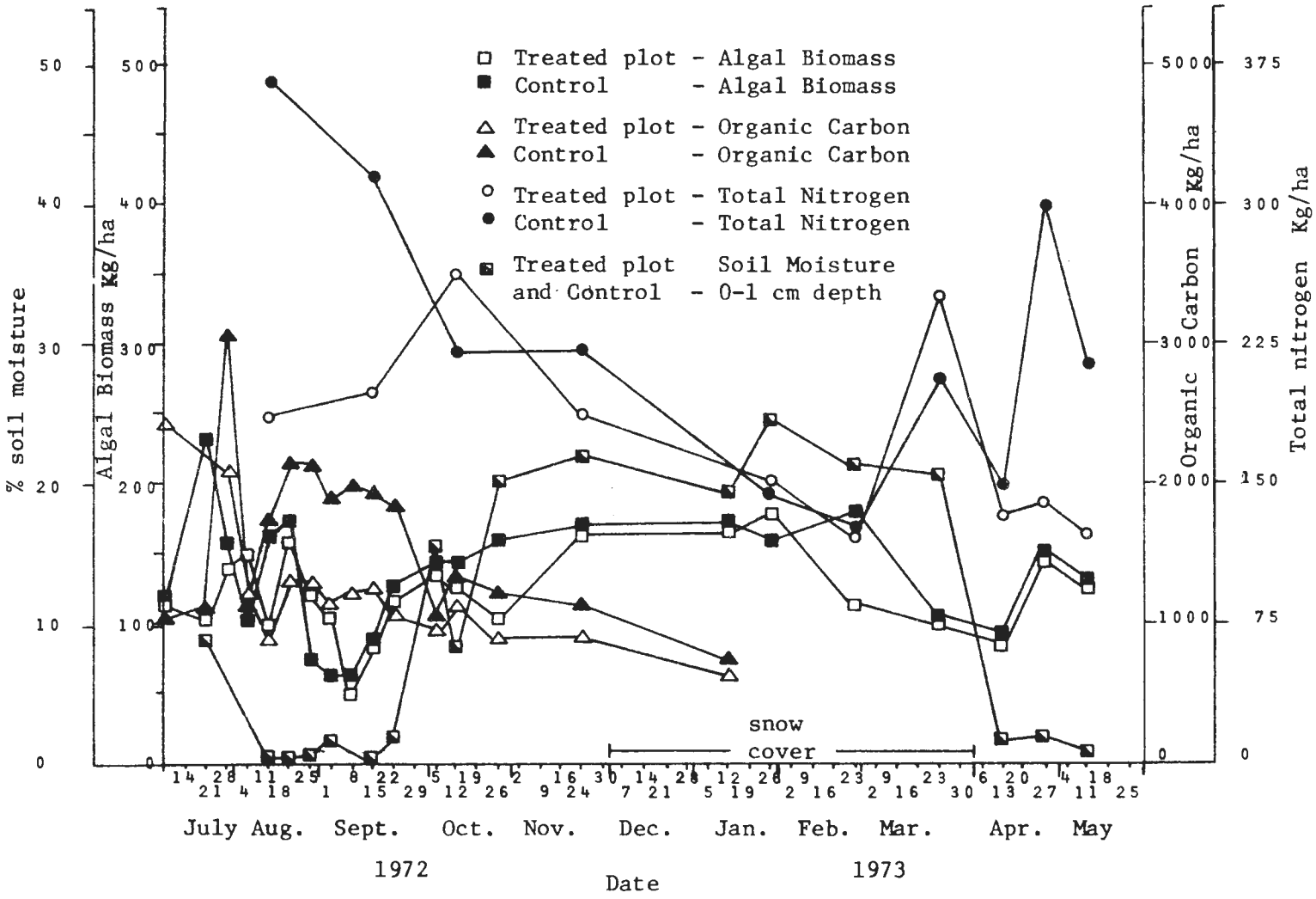


Figure 8. Sagebrush I. Biological and physical events recorded.

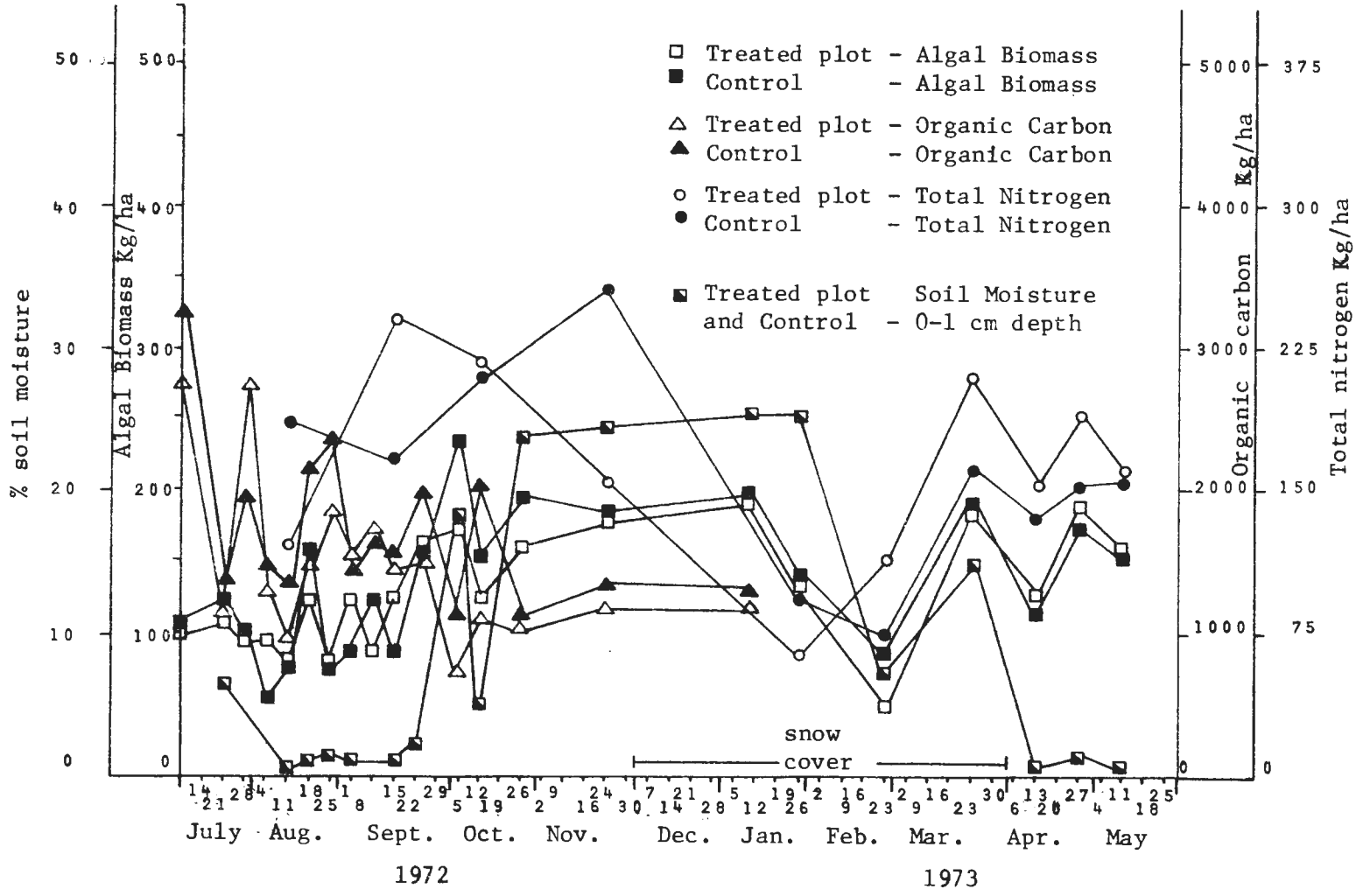


Figure 9. Greasewood. Biological and physical events recorded.

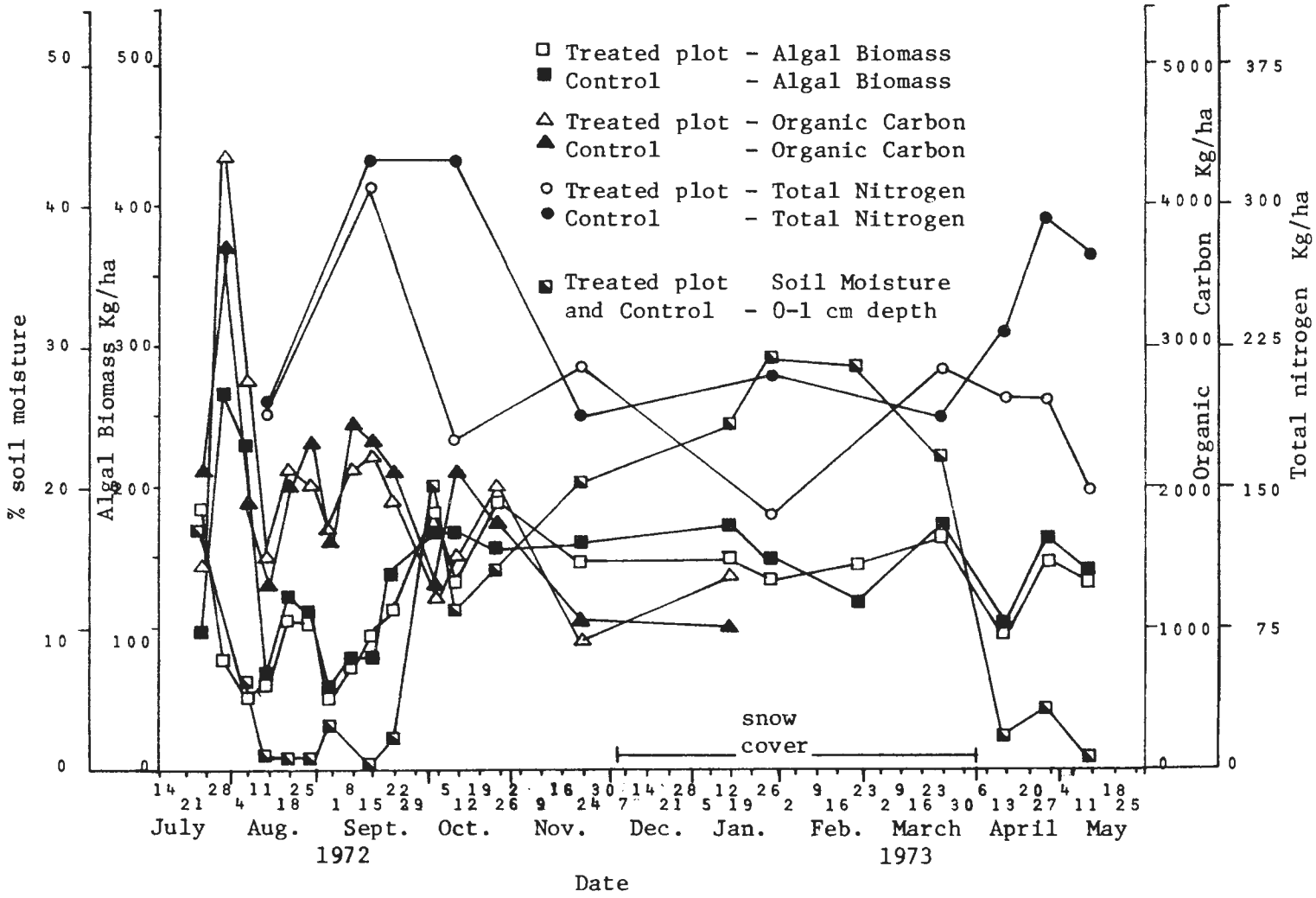


Figure 10. Sagebrush II. Biological and physical events recorded.

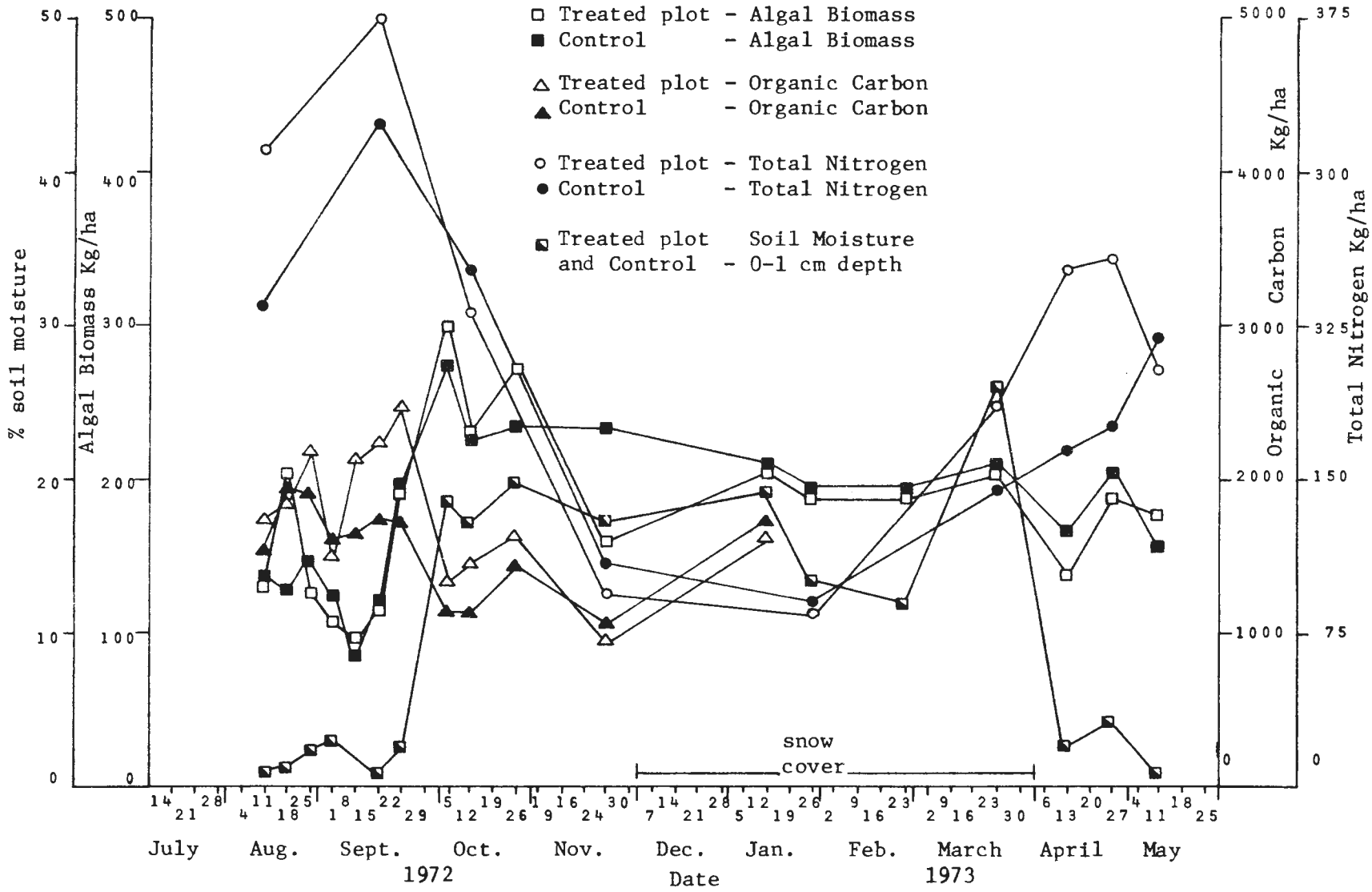


Figure 11. Crested Wheat. Biological and physical events recorded.

Statistical analyses

The data in Tables 6, 7, 8 and 9 (see Appendix) for soil moisture, algal biomass, total organic carbon and total nitrogen was subjected to linear and multiple correlations. The results of these analyses are compiled in Tables 3, 4 and 5.

Means and standard deviations. In Table 3, the sample mean ($\bar{X}$) is the average of the group it represents. The standard deviation (s) is given to provide a measure of the distribution of the data around the mean. Both $\bar{X}$ and s are expressed in the same units as the data they represent (Dixon and Massey, 1969).

T-tests. In Table 4, t is the deviation of the estimated mean from the population mean. It indicates whether the two groups being compared can be considered the same population or two distinct populations; the hypothesis of the test states that the means of the two groups are equal. Since none of the t values were significant, the groups tested cannot be considered two distinct populations.

Correlations. In Table 5, the number of data sets is expressed by N. The correlation coefficient (r) is a measure of the degree of relationship between the variables. It ranges from ±1 to 0; with +1 showing a perfect positive relationship, -1 showing a perfect negative relationship and 0 showing no relationship between the variables (Snedecor and Cochran, 1971). The coefficient of determination (r^2) is a measure of the proportion of the variability which is explained by the relationship. It ranges from +1 to 0; with +1 showing that all of the variability is explained, and 0 showing that none of the variability

Table 3. Sample means and standard deviations

Samples		$\bar{X}$	s
Soil moisture (% by weight)			
0-1 cm depth		8.5	9.1
2-3 cm depth	Combined control sites	8.1	7.7
4-5 cm depth		7.2	6.1
Algal biomass (kg/ha)			
Combined control sites		145.7	53.3
Total organic carbon (kg C/ha)			
Combined control sites		1678.4	406.2
Total nitrogen (kg N/ha)			
Combined control sites		224.8	112.9

Table 4. Sample T-tests

Data tested	Groups compared	N	$\bar{X}$	t
Total nitrogen	Sagebrush I & II	38	176.4	-1.69
	Greasewood & crested wheat	37	154.3	
Organic carbon	Sagebrush I & II	61	1698.5	-.669
	Greasewood & crested wheat	54	1623.4	
Soil moisture	Sagebrush I & II	72	10.8	-.678
0-1 cm depth	Greasewood & crested wheat	70	9.7	
Algal biomass	Sagebrush I & II	43	141.8	1.04
	Greasewood & crested wheat	40	153.5	

Table 5. Sample correlations

	N	r^2	r	Level of significance
Single regression				
Algal biomass vs. soil moisture 0-1 cm depth	40	0.388	0.623	.01
Algal biomass vs. soil moisture 2-3 cm depth	40	0.298	0.546	.01
Algal biomass vs. soil moisture 4-5 cm depth	40	0.251	0.501	.01
Algal biomass vs. organic carbon	44	0.204	-0.451	.01
Algal biomass vs. total nitrogen	75	0.014	-0.119	-
Multiple regression				
Algal biomass vs. organic carbon, soil moisture 0-1 cm depth	91	0.332	0.563	.01
Algal biomass vs. organic carbon, soil moisture 2-3 cm depth	91	0.004	-0.011	-
Algal biomass vs. organic carbon, soil moisture 4-5 cm depth	89	0.103	-0.288	.01
Algal biomass vs. total nitrogen, soil moisture 0-1 cm depth	75	0.236	0.482	.01
Algal biomass vs. total nitrogen, soil moisture 2-3 cm depth	75	0.121	-0.335	.01
Algal biomass vs. total nitrogen, soil moisture 4-5 cm depth	73	0.125	-0.345	.01
Algal biomass vs. organic carbon, total nitrogen, soil moisture 0-1 cm depth	32	0.557	0.716	.01
Algal biomass vs. organic carbon, total nitrogen, soil moisture 2-3 cm depth	32	0.233	-0.369	.05
Algal biomass vs. organic carbon, total nitrogen, soil moisture 4-5 cm depth	30	0.136	-0.273	-

is explained by the relationship. This correlation does not necessarily provide proof of a causal relationship. The level of significance states the probability of there being no actual correlation. Where no level of significance is given, there is not adequate probability to state that a relationship between the variables actually does exist.

In all of the correlations where soil moisture is used as one of the variables, the 0-1 cm depth demonstrates a better relationship with the other variables than does the 2-3 cm or 4-5 cm depths. In correlating algal biomass with total organic carbon and algal biomass with total nitrogen, both indicate a negative relationship. The correlation of the algal biomass and total nitrogen data is so low that no definite relationship can be assumed.

By correlating algal biomass with total organic carbon, total nitrogen and soil moisture at the 0-1 cm depth, it was found that 55.7% of the variability is accounted for. Periods of high soil moisture should increase algal growth and both carbon and nitrogen fixation, but these periods also provide adequate moisture for decomposition which would release these same elements into the atmosphere. This decomposition factor may account for the negative and low correlations found for these parameters.

CONCLUSIONS

1. The type of vascular vegetation present appears to be independent of the amount of soil crust cover or algal biomass present in the surface 1 cm of soil.

2. The recovery rate of soil algae after lethal treatment (methyl bromide), without physical disruption, seems complete in less than 12 months.

3. The amount of lichenized soil crust visible appears to be independent of the amount of soil algae present.

4. There was more degradation of chlorophyll A in the summer than in the winter.

5. Soil moisture at the 0-1 cm soil depth explains more variability with algal biomass, than does soil moisture at the 2-3 cm or 4-5 cm depths.

6. There appears to be no correlation between total nitrogen of the 0-1 cm soil depth and algal biomass.

7. Algal biomass appears to maintain the most consistant level of activity under light snow cover.

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APPENDIX

Burk's Nitrogen-free Ion Agar Medium
(Burk and Lineweaver, 1930)

Dissolve the following components in 500 ml of glass-distilled water:

Potassium Phosphate (monohydrogen)	0.4 g
Potassium Phosphate (dihydrogen)	0.1 g
Magnesium Sulfate	0.1 g
Sodium Chloride	0.1 g
Calcium Sulfate	0.05 g
Ferric Sulfate	0.005 g
Agar	7.5 g

Euglena Agar Medium (Starr, 1964)

Dissolve the following components in 1000 ml of glass-distilled water:

Sodium Acetate	1.0 g
Beef Extract	1.0 g
Tryptone	2.0 g
Yeast Extract	2.0 g
Calcium Chloride	0.01 g
Agar	15.0 g

Bristol's Medium (Starr, 1964)

For each 1000 ml of medium required place the following amounts of stock solutions in 938 ml of Pyrex-distilled water.

# of ml	Stock solution	
10	$NaNO_3$	10.0gm/400ml
10	$CaCl_2$	1.0gm/400ml
10	$MgSO_4.7H_2O$	3.0gm/400ml
10	K_2HPO_4	3.0gm/400ml
10	KH_2PO_4	7.0gm/400ml
.05	$FeCl_3$	1.0gm/100ml
2	P IV metal solution	see below

solidify with 15gm of agar per liter, if desired.

P IV Trace Metal Mix
(Provasoli and Pintner, 1959)

$FeCl_3 \cdot 6H_2O$	0.097gm
$MnCl_2 \cdot 4H_2O$	0.041gm
$ZnCl_2$	0.005gm
$CoCl_2 \cdot 6H_2O$	0.002gm
Na_2MoO_4	0.004gm
Na2EDTA	0.750gm

Table 6. Summary of algal crust analyses--sagebrush I

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	07	07	39.2	123.4	149.4	-	-	-	2474.7	-
C				39.2	123.4	149.4	-	-	-	1084.0	-
X	72	07	21	35.4	111.6	171.6	8.3	7.4	3.6	1246.3	-
C				75.9	239.2	136.7	8.3	7.4	3.6	1166.3	-
X	72	07	28	46.5	146.6	131.6	-	-	-	2135.2	-
C				51.3	161.5	119.5	-	-	-	3074.3	-
X	72	08	04	50.6	159.5	133.7	-	-	-	1252.3	-
C				35.4	111.6	131.1	-	-	-	1193.3	-
X	72	08	11	30.4	95.7	86.2	0.7	1.2	1.6	988.3	152.4
C				56.0	176.4	61.3	0.7	1.2	1.6	1709.2	302.7
X	72	08	18	51.3	161.5	130.1	0.6	1.0	1.9	1393.0	-
C				56.3	177.4	128.6	0.6	1.0	1.9	2124.1	-
X	72	08	25	35.8	112.6	131.1	1.0	1.3	1.3	1235.4	-
C				25.3	79.7	128.1	1.0	1.3	1.3	2148.8	-
X	72	09	01	35.8	112.8	120.1	2.3	3.6	3.7	1170.6	-
C				20.3	63.9	116.7	2.3	3.6	3.7	1820.3	-
X	72	09	08	15.2	47.8	150.8	-	-	-	1211.0	-
C				20.3	63.9	197.4	-	-	-	1982.9	-
X	72	09	15	26.5	83.5	162.5	0.9	1.2	1.8	1309.6	160.7
C				26.5	83.5	159.0	0.9	1.2	1.8	1921.3	262.3
X	72	09	22	41.1	129.6	150.9	2.5	4.7	2.6	1169.5	-
C				41.1	129.6	172.0	2.5	4.7	2.6	1901.3	-

Table 6. Continued

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	10	05	46.5	146.6	92.7	15.2	12.6	2.8	837.7	-
C				46.5	146.6	82.0	15.2	12.6	2.8	1094.6	-
X	72	10	12	41.1	129.6	133.2	9.3	9.5	8.4	1193.9	221.3
C				45.9	144.6	121.0	9.3	9.5	8.4	1374.1	188.5
X	72	10	26	35.8	112.8	127.6	20.0	12.0	14.0	1037.5	-
C				51.3	161.6	130.1	20.0	12.0	14.0	1293.3	-
X	72	11	24	50.9	160.3	108.8	26.0	45.0	22.0	902.3	155.6
C				56.0	176.4	125.1	26.0	45.0	22.0	1066.6	182.8
X	73	01	13	-	-	-	20.4	20.4	20.4	-	-
C				57.3	169.2	074.4	20.4	20.4	20.4	711.2	-
X	73	01	25	59.3	177.9	124.3	25.0	15.5	14.5	-	121.9
C				50.9	152.7	062.6	25.0	15.5	14.5	-	117.8
X	73	02	24	35.8	112.8	138.2	22.5	36.0	23.0	-	105.6
C				60.8	191.4	136.7	22.5	36.0	23.0	-	116.5
X	73	03	23	50.6	151.8	52.3	21.0	32.0	28.0	-	208.2
C				50.6	151.8	43.0	21.0	32.0	28.0	-	171.2
X	73	04	10	26.5	83.5	127.1	1.6	5.5	9.7	-	104.2
C				30.4	95.7	61.8	1.6	5.5	9.7	-	123.0
X	73	04	27	45.9	144.6	53.3	2.0	7.2	13.0	-	118.7
C				50.6	151.8	43.0	2.0	7.2	13.0	-	250.1
X	73	05	10	40.5	127.6	76.1	0.7	1.0	1.5	-	103.6
C				41.1	129.6	76.1	0.7	1.0	1.5	-	178.9

Table 7. Summary of algal crust analyses--greasewood

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	07	07	30.7	96.5	84.0	-	-	-	2639.3	-
C				50.5	96.1	116.3	-	-	-	3240.3	-
X	72	07	21	35.8	112.6	109.6	6.8	9.7	9.1	1060.3	-
C				40.5	127.6	101.6	6.8	9.7	9.1	1318.0	-
X	72	07	28	30.4	95.7	104.3	-	-	-	2676.3	-
C				30.4	95.7	72.1	-	-	-	1962.6	-
X	72	08	04	30.4	95.7	68.9	-	-	-	1247.9	-
C				15.2	47.8	105.3	-	-	-	1199.3	-
X	72	08	11	25.3	79.7	62.9	0.5	1.7	-	918.4	101.3
C				25.3	79.2	78.0	0.5	1.7	-	1355.9	157.8
X	72	08	18	41.1	129.6	127.5	0.1	1.2	1.8	1518.6	-
C				50.6	159.5	105.3	0.1	1.2	1.8	2117.3	-
X	72	08	25	25.3	79.7	110.4	1.1	1.7	2.7	1819.1	-
C				25.3	79.7	116.6	1.1	1.7	2.7	2249.0	-
X	72	09	01	35.8	112.8	84.7	11.0	10.2	12.2	1468.6	-
C				26.5	83.5	84.2	11.0	10.2	12.2	1416.8	-
X	72	09	08	26.5	83.5	84.6	-	-	-	1721.6	-
C				35.8	112.8	127.6	-	-	-	1734.5	-
X	72	09	15	35.8	112.8	113.1	1.5	2.4	6.4	1424.2	201.2
C				26.5	83.5	105.8	1.5	2.4	6.4	1505.4	138.0
X	72	09	22	51.3	161.6	123.0	2.4	6.5	9.8	1663.5	-
C				51.3	161.6	108.9	2.4	6.5	9.8	2003.3	-

Table 7. Continued

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	10	05	56.0	176.4	57.7	17.4	13.6	10.0	794.1	-
C				75.9	239.2	111.9	17.4	13.6	10.0	1130.9	-
X	72	10	12	41.1	129.6	48.1	4.1	6.5	6.4	1298.3	178.3
C				46.5	146.6	41.0	4.1	6.5	6.4	2004.2	175.7
X	72	10	26	50.9	160.3	108.8	24.0	15.2	14.4	1158.3	-
C				61.4	193.4	91.6	24.0	15.2	14.4	1109.6	-
X	72	11	24	56.0	176.4	101.3	24.0	7.0	17.5	1202.4	125.1
C				56.0	176.4	101.3	24.0	7.0	17.5	1293.7	216.4
X	73	01	13	-	-	-	25.6	25.6	25.6	-	-
C				60.8	191.4	72.2	25.6	25.6	25.6	1214.4	-
X	73	01	25	45.9	137.7	35.9	25.0	26.0	24.5	-	52.1
C				45.9	137.7	11.2	25.0	26.0	24.5	-	78.8
X	73	02	24	30.4	95.7	52.7	7.5	15.5	20.0	-	96.9
C				15.2	47.8	27.3	7.5	15.5	20.0	-	58.3
X	73	03	23	60.8	191.4	82.0	16.0	25.0	30.0	-	146.8
C				60.8	191.4	63.3	16.0	25.0	30.0	-	146.8
X	73	04	10	45.9	137.7	53.8	0.9	1.6	3.8	-	128.3
C				41.1	129.6	101.2	0.9	1.6	3.8	-	114.5
X	73	04	27	60.8	191.4	8-.0	2.5	10.2	11.8	-	159.5
C				56.0	176.4	71.9	2.5	10.2	11.8	-	118.1
X	73	05	10	51.3	161.6	50.6	0.7	1.1	1.7	-	142.8
C				51.3	161.6	59.2	0.7	1.1	1.7	-	138.1

Table 8. Summary of algal crust analyses--sagebrush II

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	07	21	57.2	181.2	110.5	16.9	12.5	6.1	1400.5	-
C				34.4	108.4	117.3	16.9	12.5	6.1	2013.5	-
X	72	07	28	25.3	79.7	201.5	-	-	-	4398.1	-
C				86.1	271.1	116.0	-	-	-	3691.1	-
X	72	08	04	15.2	47.8	136.1	-	-	-	2726.3	-
C				75.9	239.2	108.8	-	-	-	1919.1	-
X	72	08	11	20.3	63.8	87.6	1.1	2.9	4.5	1471.8	165.0
C				20.3	63.8	135.6	1.1	2.9	4.5	1309.5	171.5
X	72	08	18	36.1	113.7	138.2	1.2	1.5	2.2	2037.9	-
C				40.5	127.6	165.0	1.2	1.5	2.2	2025.4	-
X	72	08	25	36.1	113.7	134.7	1.1	1.8	3.1	2046.6	-
C				35.8	112.6	190.9	1.1	1.8	3.1	2364.8	-
X	72	09	01	15.2	47.8	126.1	3.2	2.7	2.4	1676.0	-
C				15.2	47.8	182.7	3.2	2.7	2.4	1642.7	-
X	72	09	08	26.5	83.5	73.6	-	-	-	2169.7	-
C				26.5	83.5	116.4	-	-	-	2491.7	-
X	72	09	15	30.7	96.7	146.8	0.8	1.5	3.0	2372.3	260.4
C				26.5	83.5	205.0	0.8	1.5	3.0	2380.9	270.6
X	72	09	22	41.1	129.6	120.0	2.6	3.9	3.5	1914.3	-
C				46.5	146.6	188.3	2.6	3.9	3.5	2059.1	-

Table 8. Continued

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	10	05	61.1	192.5	98.7	22.0	18.6	4.6	1200.2	-
C				56.0	176.4	142.8	22.0	18.6	4.6	1315.4	-
X	72	10	12	40.5	127.6	90.3	12.8	13.6	12.2	1486.0	146.6
C				56.0	176.4	132.1	12.8	13.6	12.2	2084.3	271.2
X	72	10	26	45.9	144.6	100.8	24.4	17.6	18.0	2018.2	-
C				50.7	159.7	122.7	24.4	17.6	18.0	1691.7	-
X	72	11	24	45.9	144.6	79.5	20.0	18.0	16.0	927.6	176.4
C				51.3	161.6	82.5	20.0	18.0	16.0	1008.7	157.3
X	73	01	13	45.9	144.6	89.1	24.0	24.0	24.0	1498.8	-
C				56.0	176.4	234.4	24.0	24.0	24.0	1040.9	-
X	73	01	25	45.9	137.7	60.8	29.0	46.0	29.0	-	114.3
C				50.6	151.8	98.2	29.0	46.0	29.0	-	179.3
X	73	02	24	45.0	144.6	60.8	28.0	43.0	31.0	-	-
C				40.5	127.6	121.0	28.0	43.0	31.0	-	-
X	73	03	23	56.0	176.4	62.0	23.0	28.0	25.0	-	180.2
C				55.7	175.4	71.9	23.0	28.0	25.0	-	158.5
X	73	04	10	30.7	96.7	89.6	2.5	9.0	10.2	-	164.5
C				35.8	112.8	74.1	2.5	9.0	10.2	-	192.0
X	73	04	27	50.6	151.8	54.3	4.2	17.0	18.0	-	160.5
C				55.7	175.4	71.9	4.2	17.0	18.0	-	239.5
X	73	05	10	41.1	129.6	91.0	1.1	1.9	2.7	-	123.6
C				45.9	137.7	49.8	1.1	1.9	2.7	-	227.3

Table 9. Summary of algal crust analyses--crested wheat

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	72	08	11	42.0	132.3	22.0	1.1	2.1	5.5	1692.4	253.4
C				45.8	144.3	61.5	1.1	2.1	5.5	1527.2	195.8
X	72	08	18	65.8	207.3	61.8	1.5	1.6	2.3	1845.0	-
C				41.4	129.6	65.8	1.5	1.6	2.3	1981.9	-
X	72	08	25	40.8	128.6	87.1	1.4	1.8	2.8	2196.1	-
C				46.5	146.6	106.2	1.4	1.8	2.8	1910.0	-
X	72	09	01	35.2	110.9	88.6	3.4	3.5	2.7	1470.5	-
C				40.5	127.6	30.4	3.4	3.5	2.7	1593.7	-
X	72	09	08	30.7	96.7	65.3	-	-	-	2134.5	-
C				26.5	83.5	59.7	-	-	-	1615.5	-
X	72	09	15	41.1	129.6	83.5	0.8	1.0	2.3	2208.0	320.4
C				41.1	129.6	72.9	0.8	1.0	2.3	1726.9	267.3
X	72	09	22	61.1	192.5	81.0	2.9	4.2	3.7	2539.4	-
C				61.1	192.5	59.7	2.9	4.2	3.7	1755.8	-
X	72	10	05	96.2	303.0	54.4	19.6	19.4	4.8	1298.9	-
C				86.1	271.2	30.9	19.6	19.4	4.8	1161.1	-
X	72	10	12	70.9	223.3	61.8	17.0	15.2	15.6	1456.7	192.8
C				70.9	223.3	93.7	17.0	15.2	15.6	1152.7	221.8
X	72	10	26	86.1	271.2	96.2	20.2	18.0	18.2	1617.2	-
C				75.9	239.2	72.9	20.2	18.0	18.2	1529.2	-
X	72	11	24	51.3	161.6	34.4	16.6	14.8	17.0	1047.6	76.5
C				71.2	224.3	25.3	16.6	14.8	16.0	1066.0	84.1

Table 9. Continued

Site X-Treated plot C-Control	Date YY	MM	DD	Chloro-phyll A Mg/m^2	Algal biomass Kg/ha	Pheo-phytin Mg/m^2	Soil moisture % by weight 0-1 cm	2-3 cm	4-5 cm	Total organic carbon KgC/ha	Total nitrogen KgN/ha
X	73	01	13	-	-	-	20.0	20.0	20.0	-	-
C				66.1	208.2	52.9	20.0	20.0	20.0	1670.2	-
X	73	01	25	-	-	-	14.0	16.0	14.0	-	-
C				60.8	182.4	23.3	14.0	16.0	14.0	-	71.6
X	73	02	24	-	-	-	13.0	18.0	14.0	-	-
C				60.8	182.4	34.4	13.0	18.0	14.0	-	-
X	73	03	23	65.8	207.3	39.4	27.4	26.0	35.0	-	162.4
C				65.8	207.3	34.9	27.5	26.0	35.0	-	127.2
X	73	04	10	45.9	137.7	29.6	2.5	7.3	14.5	-	210.3
C				51.3	161.6	36.7	2.5	7.3	14.5	-	130.5
X	73	04	27	61.1	192.4	24.5	4.2	15.1	18.0	-	213.0
C				65.8	207.3	66.4	4.2	15.1	18.0	-	140.5
X	73	05	10	56.0	176.4	24.5	1.6	5.4	5.4	-	170.1
C				51.3	161.6	66.3	1.6	5.4	5.4	-	181.2

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