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NUTRITIONAL RESPONSE OF WILDLIFE
FORAGES TO MUNICIPAL SLUDGE
APPLICATION

presented by

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has been accepted towards fulfillment
of the requirements for

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NUTRITIONAL RESPONSE OF WILDLIFE FORAGES TO MUNICIPAL SLUDGE APPLICATION

By

Henry Campa, III

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ABSTRACT

NUTRITIONAL RESPONSE OF WILDLIFE
FORAGES TO MUNICIPAL SLUDGE
APPLICATION

By

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Municipal sewage sludge, obtained from the Cadillac, Michigan sewage treatment facility, was applied to study areas in a 4-year-old jack pine (*Pinus banksiana*) clear-cut. Six 2 ha plots were delineated in the clear-cut, and 3 were randomly selected and treated with approximately 11 metric dry tons/ha of sludge during May, 1980. Samples of selected plant species were collected in summer and late fall. Crude protein, ether extract, ash, phosphorus, Goering and VanSoest fiber analyses, hemicellulose, cellulose, and *in vitro* dry matter digestibility values were used to indicate the nutritional quality of selected plant species. Samples were also analyzed for concentrations of 13 elements. Changes in annual productivity were monitored on both sludge-treated and control areas.

Results indicated total annual productivity was significantly greater on sludge-treated areas than control areas. Crude protein content for all species (except jack pine) was significantly greater on sludge-treated areas than

control areas for both seasons. Phosphorus analysis showed only herbaceous species and all fall woody species had significantly greater levels on sludge-treated areas than control areas. Goering and VanSoest fiber analyses, hemicellulose, and cellulose analysis indicated a trend of lower fiber levels and thus greater digestibility for plants on sludge-treated areas. Elemental analysis indicated herbaceous species on sludge-treated areas accumulated significantly greater concentrations of more elements than other plant groups. Levels of these elements are not believed to present any toxicity problems to wildlife.

Plant species which showed the greatest increase in nutritional qualities and elements on sludge-treated areas also displayed an increase in production. This was commonly due to: 1) depth of the root system of a species and/or 2) speed at which a species can normally assimilate nutrients.

These results indicate that sludge application to appropriate forested lands could serve as a viable solution to both sludge disposal and habitat improvement. Future research should focus on the length of time nutritional benefits can be expected with a single application of sludge.

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INTRODUCTION

As the human population has grown, the problem of waste accumulation has also increased. Disposing of large volumes of municipal waste has caused public concern and an increasing demand for environmentally safe methods of waste disposal. Presently, municipal wastewater treatment plants are producing approximately 18 to 91 million metric tons of sludge (the solids accumulated and concentrated during wastewater treatment) annually in the U.S. (Lang 1981 unpubl. data). With such a large volume of waste, problems are arising in obtaining sites and local public approval for implementing any of the acceptable sludge management alternatives.

Currently, the alternatives for disposing of this vast amount of sludge are limited to incineration, landfilling, ocean disposal, and land application. If disposal sites are available and liquid sludges are accepted, landfilling may be an economical alternative. Hauling distances, however, may be a limiting factor in implementing landfilling as a sludge disposal method. If sites are not available, incineration is the method employed most often if air quality criteria allow it.

Ocean disposal is expected to be phased out, since dumpers do not meet the ocean dumping requirements. Due to the limitations of these disposal methods, with rising fuel costs, the land application of sludge is being implemented and investigated as a primary method of sludge disposal for the future (Bastian 1977).

Because of the growing public desire and need to recycle resources, municipal sewage sludge produced by modern sewage treatment techniques has been applied to agricultural lands, and the effects on plant quality and productivity studied. By using this means of sludge disposal, society can capitalize on a viable, economical and readily available source of nutrients for crop production (Urie 1979). Because sewage sludge provides nitrogen and other nutrients, researchers have observed that when sludge is applied to agricultural crops, their productivity and nutritive quality have been enhanced (Blessin and Garcia 1979). In addition to nitrogen, these waste products are a source of phosphorus, calcium, zinc, iron, and sulphur for plants. Because of some of the additional elements present, problems do exist with the land application of sewage sludge. The major concerns with applying sludge to land are: 1) aesthetics, 2) the possibility of introducing deleterious chemicals (such as heavy metals) and persistent organic compounds, and 3) pathogenic microorganisms occuring in the human food chain.

When sludge is applied to agricultural lands, there is concern that the marketed portion of crops grown on sludge-treated soils will be in direct or indirect contact with the sludge. Despite the fact that both aerobic and anaerobic sewage treatment processes are quite effective in removing pathogens and toxic chemicals, no technique is 100% effective. The possibility of heavy metal accumulation in foodstuffs remains a significant cause for concern (Bitton et al. 1980). Sagik et al. (1979) stated that while arsenic, copper, lead, mercury, nickel, selenium and zinc are of concern, cadmium poses the greatest human health risk. They also stated, however, that if control is exerted on domestic sewage at point sources, requiring them to use adequate secondary treatment followed by disinfection, the resultant waste may contain lower levels of potential human pathogens and chemical contaminants. Because of such problems, researchers have sought safer alternative sludge disposal sites that will still benefit from the fertilizer effect. By using forested areas instead of croplands, the chance of toxic chemical and pathogen transfer to the human food chain is reduced (Sopper 1973). In addition, the unsightly appearance of sludged vegetation is secluded.

A primary goal of applying sludge to forest lands is to use the nutrients available in sludge to manipulate and improve wildlife habitat quality. Several researchers have documented that the application of sludge to forest lands has resulted in a significant increase in tree growth (Roth et al. 1979, Urie 1979). Plant responses produced by sludge application are quite similar to those observed with inorganic fertilizers. These comparable results are produced by the nutrients and trace elements contained in sludges and inorganic fertilizers (Braids et al. 1980). Urie (1979) stated that superior plant growth on sludge-treated areas can continue to be anticipated because of the resulting nitrogen reservoir in the soil.

Researchers who have studied the effects of sewage effluent or sludge application on agricultural crops and forests have found, in all instances, that the nutritive value of vegetation was improved. The nutrient component which consistently increased with waste application was crude protein (Dressler and Wood 1976, Blessin and Garcia 1979). This is a common index of forage quality among researchers (Bailey 1968, Kelsey et al. 1973, Groetz 1975, Bayoumi and Smith 1976, Bear 1978). Blessin and Garcia (1979) studied strip mines and found an increase of 2.5% in protein content after sludge was applied. Dressler and Wood (1976) noted crude protein, potassium and phosphorus were significantly higher in plants grown on effluent irrigated sites, whereas crude fiber and calcium were significantly lower. Thus, studies have shown that with the land application of sewage waste, plant quality and productivity increase.

As plants mature, however, a definite change in their chemical composition occurs, eventually causing nutrient quality to decline. Sludge application may accelerate this change due to the influx of nutrients causing plants to reach maturity earlier. An increase in fiber components as plants mature is an example of how nutritive quality declines with maturity (Cook and Harris 1950). Van Soest (1965) stated that as the fiber components of plants increased with maturity, forage digestibility declined. The level of digestibility was closely related to the chemical composition of plants.

Presently, recommended rates for the land application of sludge are based on the fertilizer value (nitrogen, phosphorus, and potassium) and on the concentrations of trace metals present in sludge. While appropriate levels of nitrogen, phosphorus, and potassium may enhance plant productivity and quality, excessive amounts of metals may produce a negative effect. Sommers (1977a) stated that when zinc, copper, lead, nickel, and cadmium are applied to soils in excessive amounts, plant yield or quality of food or fiber may be impaired.

Because municipal waste land application may produce benefits such as improved plant nutritional value, it could be an established waste treatment and habitat improvement technique for wildlife management (Urie 1979). Other researchers have suggested that organic waste application may be the beginning of reclamation programs

(Lejcher and Kunkle 1973). It may also be part of a productive process like inorganic fertilization. Most importantly, however, land application processes return nutrients to their natural cycles and dispose of waste in a manner in which any long-term adverse impact could be monitored and corrected if necessary (Freshman 1977). Because of such benefits, and the urgent need for a safer method of sludge disposal, the practice of sludge application to appropriate forested lands should be researched for consideration as a viable method of habitat improvement.

OBJECTIVES

The main objective of this study was to determine the effects of a single sludge application on the nutritional quality, in terms of chemical constituents and digestibility of selected wildlife forage species and parts of these plant species during summer and fall. A second objective of the study was to determine how sludge application would affect annual productivity. Production was investigated since the influx of nutrients may significantly increase growth as well as the quality of vegetation.

STUDY AREA DESCRIPTION

The study area was located in the S½ N¼ of Section 15, T22N, R10W in Wexford County, approximately 6.4 km north of Cadillac, Michigan (Figure 1). The site was a 20 ha, 5-year old jack pine clear-cut which had also been roller chopped.

This site is within the Cadillac Hilly Upland physiographic region of Michigan's lower peninsula. The area is in the watershed of the Muskegon River which drains westward to the eastern shore of Lake Michigan (Sommers 1977b).

The surface formations of the area are primarily a medium altitude outwash plain of stratified sand and gravel deposits. These materials were deposited in the Pleistocene epoch (Sommers 1977b).

Soils on the study site were of the Graycalm and Montcalm series. Both soil types are sandy and range from being excessively drained (Graycalm) to well drained (Montcalm). Graycalm soils are very strongly to slightly acidic while Montcalm soils are considered medium to slightly acidic (Corder 1979). The litter layer is poorly developed with no A-2 horizon present, indicated that cultivation may have occurred within the last century. The slope is

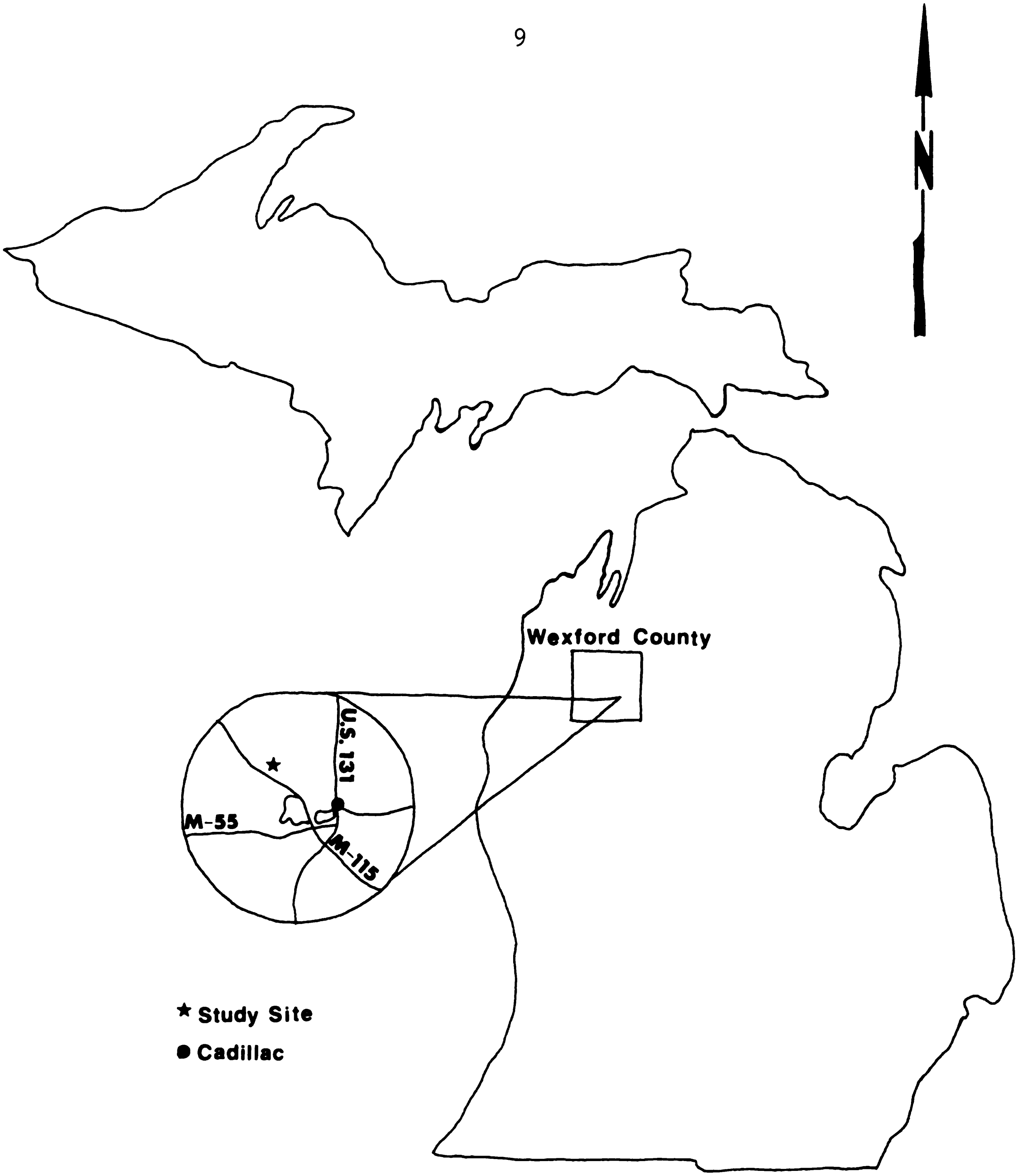

Figure 1. Location of study site near Cadillac, Michigan.

gradual and to the west, with a low spot in the southwest corner of the site.

The climate of Cadillac alternates between continental and semi-marine in character, as the weather patterns change. Lake Michigan influences Cadillac's climate primarily during the late fall and winter months when westerly winds bring increased cloudiness and milder minimum temperatures. Average annual temperature and precipitation for this area are 5.8°C and 76 cm respectively. Mean (1928-1969) and 1980 monthly temperature and precipitation data for the study period are given in Figure 2 (Eichmeier 1963, Strommen 1974, Witehell 1980).

The existing vegetation consisted of regenerating jack pine, interspersed by clumps of pin cherry (*Prunus pennsylvanica*), black cherry (*Prunus serotina*), and choke cherry (*Prunus virginiana*). The ground cover ranged from areas of dense grasses and brambles (*Rubus*, spp.) to gaps of no vegetation.

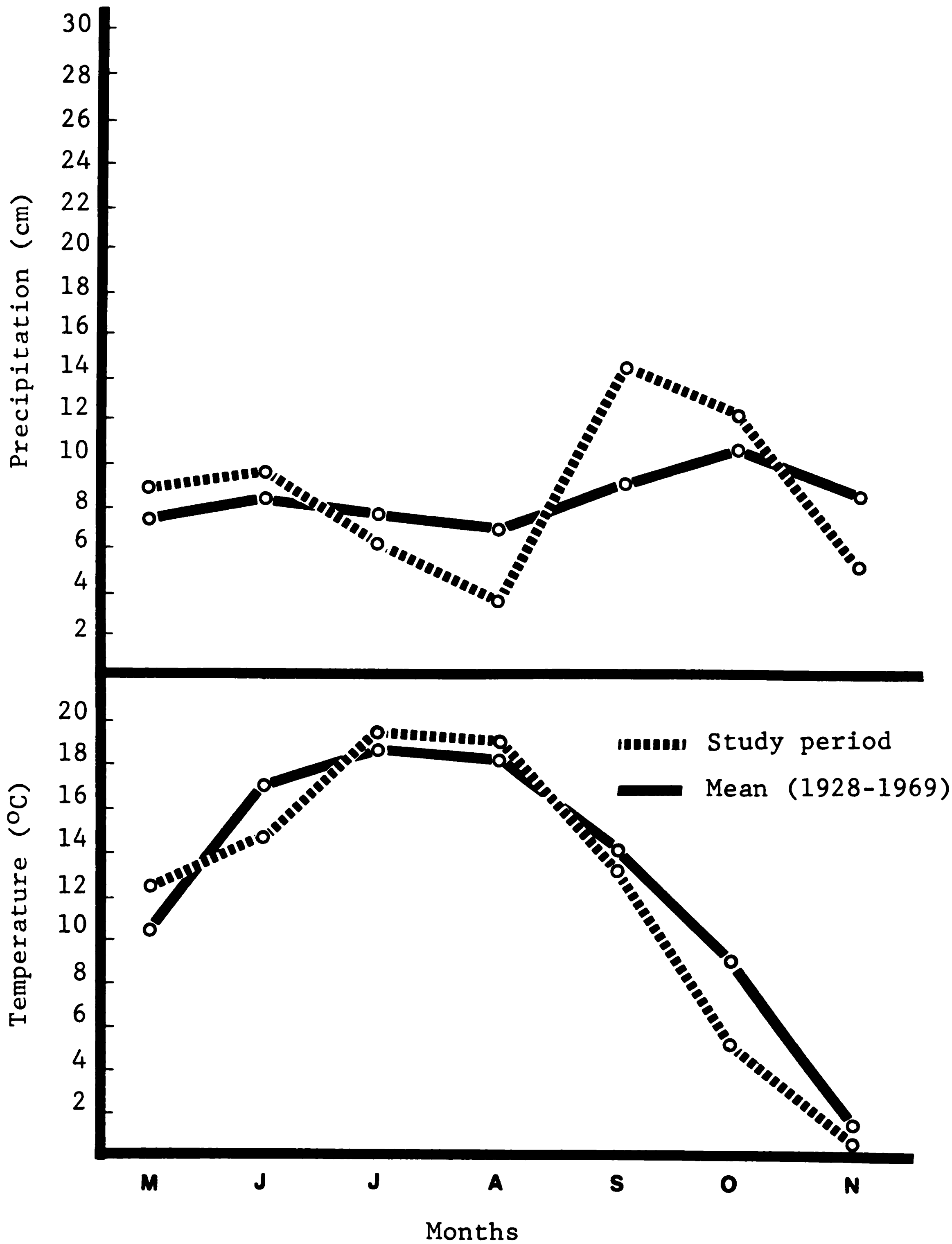

Figure 2. Mean percipitation and temperature data by month during study period, 1980.

METHODS AND MATERIALS

Experimental Design

The experimental design was six-2 ha plots located on the study site. Three of these were randomly selected for sludge-treatment in May 1980, 3 years after clear-cutting (Figure 3).

Sludge Application

During May 1980, non-industrial municipal sewage sludge was applied to treatment areas at a loading rate of approximately 11 metric dry tons/ha. This loading rate was equivalent to 481.5 kg/ha of nitrogen, 571.4 kg/ha of phosphorus, and 4.2 kg/ha of potassium. The U.S. Forest Service has determined that this nitrogen loading rate does not cause ground water levels of nitrate to exceed safe limits. Loading rates of other elements are given in Table 1.

All sludge was obtained from the sewage treatment facility at Cadillac, Michigan. It was produced by a biological secondary sewage treatment process. The sludge received approximately 90 days of anaerobic digestion prior to application. The elemental analysis of the sludge applied is shown in Table 2.

Figure 3. Location of sludge-treated and control areas on the study site.

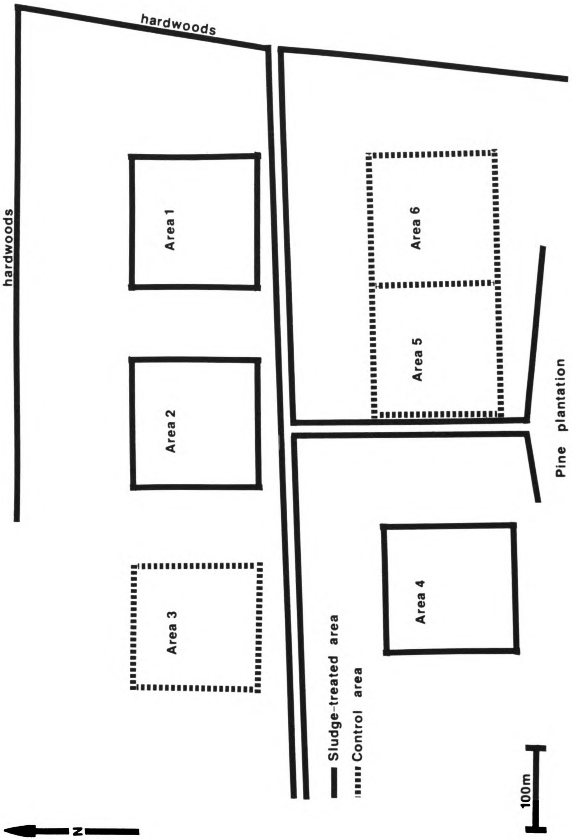
hardwoods
hardwoods
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Pine plantation
Sludge-treated area
Control area
100m
N

Figure 3.

Table 1. Mean application rates of elements to soils.

Element	Application Rate (Kg/ha)
Zn	17.0
Cd	0.6
Mn	7.4
Al	59.0
Mg	75.0
Cu	7.3
K	4.2
Ni	0.8
Cr	2.6
Na	17.0
N	481.5
P	571.4
Fe	752.4
Ca	403.7

Table 2. Mean levels of elements in municipal sludge obtained from Cadillac, Michigan, 1980.

Element	ppm
Zn	1535
Cd	56
Mn	671
Al	5388
Mg	6788
Cu	665
K	378
Ni	69
Cr	239
Na	1545
N	43800
P	52000
Fe	6.8 (%)
Ca	3.7 (%)

A portable pipeline-rain cannon system was used to distribute the sludge over the ground and litter surface of treatment areas. Sewage sludge was trucked to the study area and stored in a pit, from which it was pumped through irrigation piping, and sprayed on the areas. Each treatment area was divided into a 6 x 6 grid. The rain cannon was placed at the points of intersection within each grid so that sludge was applied relatively evenly to all treatment areas. Sludge application took 11 days.

Selection of Plant Species to be Sampled

The emphasis of this project was to determine how the land application of sludge affects the nutrient quality of vegetation in general. The plant species to be sampled were selected on the basis of their relative abundance.

Vegetation samples were collected during both summer and fall to allow for seasonal comparisons. Summer samples consisted of cherry, jack pine, brambles, orange-hawkweed (*Hieracium aurantiacum*), sedge (*Carex* spp.), and panic grass (*Panicum virgatum*). Fall samples were collected after leaf fall so chemical analyses would yield mean nutrient and element values representative of plant species during the fall and winter. These samples were confined to cherry, jack pine, and brambles, since by late fall herbaceous species are dead and often under snow cover, therefore are unavailable for wildlife consumption. Other plant species on the study site are listed in the Appendix, Table 30.

Sample Collection

Summer

The summer sampling period was conducted from mid-July to mid-August 1980. A completely randomized sampling design was used to choose the locations of all plots and starting points of transects for vegetation sampling. To determine annual productivity for cherries and jack pine all current annual growth <2 m was clipped from individual trees. Eight trees from each species were randomly selected on each area with 2 individuals selected from each of 4 height strata. The height strata for cherry and jack pine were: 0-30cm, 30-60cm, 60-90cm, >90cm, and 0-60cm, 60-90cm, 90-120cm, and >120cm respectively.

To collect bramble and panic grass samples, random plots were located and the vegetation clipped at ground level. Clipped vegetation from 5 plots was combined to compose a single sample for nutrient and element analysis for these species.

To collect orange-hawkweed and sedge, 3 transects were established on each area, running from the northern to the southern border. Each transect had 5 sampling points located 28m apart in order to collect vegetation from the entire length of an area. Approximately 100g of vegetation were collected from the closest individual(s) to each sampling point. All vegetation collected along a transect was then combined for each species to constitute 1 sample. Vegetation was collected from a large enough number of individuals so that individual plant variations in nutrient content would be minimized in the samples.

Fall

Fall samples were collected in early November, 1980. The 3 woody species collected for chemical analyses were taken along transects by the same method used to collect orange-hawkweed and sedge in the summer.

Sample Preparation

Summer

Samples were placed in paper bags and dried at 60°C to a constant weight. Samples were reweighed after drying to determine percent moisture loss. Variation in moisture content of plants collected under varying climatic conditions was not taken into consideration.

Researchers have determined that the nutritive values of various plant parts differ (Cook and Harris 1950, Dietz 1965, Bailey 1967). Cherry and jack pine leaves were separated from twigs after drying. By separating these 2 portions, values obtained through chemical analyses should represent the actual nutritive qualities of each plant part.

After parts were separated, samples were ground in a Wiley mill to pass a 1.0mm sieve. Ground samples were then stored in Whirl-paks (NASCO, Inc., Fort Atkinson, WI) for future chemical analyses.

Fall

Fall samples were handled differently than summer samples. During collection, all vegetation samples were clipped and placed in plastic bags. Samples were then frozen and stored until they could be dried and ground by methods stated previously.

Chemical Analyses

All vegetation samples were analyzed for percent dry matter, percent moisture, ash, crude protein (CP), ether extract (EE), in vitro dry matter digestibility (IVDMD), neutral-detergent fiber (NDF), acid-detergent fiber (ADF), acid-detergent lignin (ADL), and selected elements. Percent moisture and percent ash were determined by methods stated in A.O.A.C. (1975). Total nitrogen and phosphorus were determined with a Kjeldahl digestion method using a Tecator Block Digestor, Model DS-40 (Tecator, Inc., Boulder, CO). Once samples were digested, values were obtained using a Technicon Autoanalyzer II (Technicon Industrial Systems, Tarrytown, NY). Crude protein values were calculated as stated by A.O.A.C. (1975) using total nitrogen values. Ether extract (crude fat) content was determined by methods stated in A.O.A.C. (1975) modified by weighing vegetation samples into tared filter paper "packets" instead of thimbles. This modification enabled a larger number of samples to be analyzed per run. Percent EE was calculated as the weight loss in samples after extraction. Methods for NDF, ADF, and ADL analyses were those described by Goering and VanSoest (1970). In vitro dry matter digestibility was determined using the Tilley and Terry (1963) method, modified by the use of a phosphate-carbonate buffer solution to reduce foaming, and by reducing the amount of fluid used from 40ml to 10ml. Rumen fluid was obtained from a fistulated Holstein cow fed alfalfa hay and owned by Michigan State University's Department of Dairy Science.

Percent dry matter analysis was conducted by weighing 1.0-1.1g of dried, ground vegetation and putting it in aluminum pans which were then placed in an oven preheated to 100°C. Samples were dried for 24 hours, cooled in a dessicator, and then reweighed. Since each analysis dealt with only a small amount of sample, and all samples contained some moisture even after initial drying, it was imperative that the original sample weights be multiplied by percent dry matter. This calculation yielded the actual amount of vegetation used for an analysis.

The percent of cell wall constituents (CWC) are the fiber contents (hemicellulose, cellulose, and lignin) determined from NDF analysis. The cell soluble material (CSM) consisting of the soluble carbohydrates, starches, organic acids, protein and pectin was determined by subtracting CWC values from 100 (Goering and VanSoest 1970).

The hemicellulose content of vegetation samples was calculated by subtracting ADF (cellulose and lignin) values from NDF (hemicellulose, cellulose, and lignin) values. Cellulose content was calculated by subtracting ADL (lignin) values from ADF content.

Elemental analysis was conducted by the U.S. Forest Service - Michigan State University Cooperative Analytical Laboratory in East Lansing, Michigan. This analysis was conducted with a coupled plasma emission spectrophotometer (Spectrametrics, Inc., Andover, MA) (DeBolt 1980, Dahlquist and Knoll 1978).

Statistical Analysis

To determine if sludge treatment had a significant effect on the 1) nutritional quality; 2) elemental content; and 3) annual productivity of vegetation collected during both sampling periods, a 1 way analysis of variance was performed on the data for all species. Bartlett's test was conducted on all data to test for homogenity of variance. Data which had heterogeneous variances were subjected to the arc sine transformation (Steel and Torrie 1980). Two--way analysis of variance was used to determine the season-treatment interaction of the 3 plant species collected during both seasons. A significance level of $P \leq 0.10$ was chosen to determine if significant differences between sludge-treated and control areas existed.

Percent IVDMD data was used as reference to correlate fiber constituents and CSM values and IVDMD data. Correlations were made for all plant species on both sludge-treated and control areas to determine if the effects both treatments had on CSM and fiber constituent levels were related to IVDMD data.

Regression equations were derived to determine if there was a relationship between height classes and annual productivity for cherries and jack pine. All regression equations were tested for significance using an F-test. Analysis of covariance was then used to determine if there was a significant difference in annual production on sludge-treated and control areas.

RESULTS

Annual Productivity

The total annual productivity of 5 plant species <2m in height was 128% greater on sludge-treated areas than control areas. Cherries were the only species which displayed a significant increase in production with sludge application (Table 3).

The analysis of annual tree productivity by height showed a positive linear relationship between tree height and production (Table 4). Covariance analysis demonstrated that individual tree production was significantly greater on sludge-treated areas than controls for both plant species.

Crude Protein

Crude protein content was increased by sludge treatment in all plant species during both sampling periods (Table 5). Summer samples of jack pine twigs were the only species and part not to show significantly greater CP levels on sludge-treated areas.

Table 3. Above-ground net annual production (kg/ha) < 2 m height on study areas in 1980.

Species	Sludge-treated		Control		Significance
	$\bar{X}$	SE	$\bar{X}$	SE	
Cherry	2084	185	867	369	$P < 0.10$
Jack pine	478	193	175	121	$P > 0.10$
Brambles	367	30	262	152	$P > 0.10$
Panic grass	168	61	51	12	$P > 0.10$
Other	11.6	3.3	6.5	1.6	$P > 0.10$
Total	3109	236	1362	210	$P < 0.01$

Table 4. Regression equations and covariance analysis for net above-ground annual production (g dry wt) per tree height (cm) of jack pine (*Pinus banksiana*) and cherry (*Prunus* spp.) in 1980.

Species	Sludge-treated	Control
Cherry	*$y = -326 + 2.32x$ $r^2 = .12$[a]	$y = -22.5 + 1.89x$ $r^2 = .23$
Jack pine	*$y = -174 + 7.70x$ $r^2 = .67$	$y = -84.0 + 3.71x$ $r^2 = .60$

*production per individual tree was significantly different ($P < 0.0007$) from control areas according to analysis of covariance.

[a]Slopes were significant ($P < 0.10$) for both species.

Table 5. Comparisons of crude protein (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	27.87	3.51	15.65	0.57	$P < 0.100$
	Cherry twigs	8.68	0.53	6.26	0.47	$P \leq 0.050$
	Jack pine leaves	11.86	0.33	9.90	0.19	$P \leq 0.050$
	Jack pine twigs	9.67	2.57	4.67	0.13	$P \geq 0.100$
	Brambles	16.50	0.57	10.00	0.24	$P < 0.005$
	Orange-hawkweed	22.76	1.04	13.14	0.31	$P \leq 0.005$
	Sedge	12.07	0.73	6.86	0.25	$P \leq 0.005$
	Panic grass	17.14	0.68	7.20	0.20	$P \leq 0.005$
Fall						
	Cherry twigs	9.48	0.34	7.09	0.47	$P < 0.100$
	Jack pine leaves	11.11	0.20	9.67	0.33	$P \leq 0.005$
	Jack pine twigs	6.15	0.28	5.56	0.18	$P \leq 0.050$
	Brambles	7.66	0.53	5.62	0.29	$P \leq 0.050$

Panic grass showed the greatest increase (133%) in CP content on sludge-treated areas during the summer. Analysis of fall samples showed brambles had the greatest response to sludge-treatment, increasing CP by 36%. All fall samples showed less variation in protein content between treatments than did summer samples.

Phosphorus

Phosphorus content was consistently higher on sludge-treated areas than controls for all species during both sampling periods (Table 6). Significantly greater phosphorus levels were found on sludge-treated areas than control areas for all species except cherry, jack pine, and bramble summer samples. Sedge and panic grass showed the greatest increase in phosphorus on sludge-treated areas. The phosphorus content was 140% and 126% higher on sludge-treated areas than controls for these species respectively.

Ether Extract

Ether extract content was not consistantly greater on sludge-treated areas than controls (Table 7). Panic grass was the only species to show significantly greater EE content on sludge-treated areas than controls. Ether extract content was 9% higher on sludge-treated areas. Orange-hawkweed displayed significantly greater values on control areas.

Table 6. Comparisons of phosphorus (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	2973	133	2626	480	$P > 0.100$
	Cherry twigs	2108	399	1625	195	$P > 0.100$
	Jack pine leaves	1925	522	1773	389	$P > 0.100$
	Jack pine twigs	2755	1129	1453	201	$P > 0.100$
	Brambles	3565	1013	2125	81	$P > 0.100$
	Orange-hawkweed	5805	1382	3093	152	$P \leq 0.010$
	Sedge	3115	687	1300	227	$P \leq 0.100$
	Panic grass	2417	427	1069	92	$P \leq 0.050$
Fall						
	Cherry twigs	1395	45	1127	65	$P \leq 0.100$
	Jack pine leaves	1305	35	1210	30	$P \leq 0.100$
	Jack pine twigs	1016	20	905	16	$P \leq 0.005$
	Brambles	1318	32	806	61	$P \leq 0.005$

Table 7. Comparisons of ether extract content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	13.62	0.59	14.38	0.24	$P > 0.100$
	Cherry twigs	9.32	0.27	9.19	0.38	$P > 0.100$
	Jack pine leaves	16.73	0.73	17.14	0.99	$P > 0.100$
	Jack pine twigs	16.87	0.29	17.79	1.09	$P > 0.100$
	Brambles	11.55	0.24	11.57	0.28	$P > 0.100$
	Orange-hawkweed	14.35	0.21	15.05	0.28	$P \leq 0.050$
	Sedge	8.47	0.23	8.18	0.09	$P \geq 0.100$
	Panic grass	9.56	0.26	8.78	0.27	$P \leq 0.0100$
Fall						
	Cherry twigs	9.93	0.20	8.91	0.36	$P \leq 0.100$
	Jack pine leaves	16.52	0.35	17.30	0.34	$P \leq 0.005$
	Jack pine twigs	26.64	1.63	23.92	0.64	$P \geq 0.100$
	Brambles	7.70	0.24	8.61	0.22	$P \leq 0.005$

Analysis of fall samples showed cherry twigs were the only species and part to have significantly greater EE content on sludge-treated areas than controls (an 11% increase). Jack pine leaves and brambles showed significantly greater EE levels on control areas.

Ash

Analysis of summer samples showed only jack pine twigs had significantly greater ash content (an 11% increase) on sludge-treated areas than controls (Table 8). Those species which had significantly greater ash content on control areas were sedge and fall jack pine leaf samples.

In vitro Dry Matter Digestibility

In vitro dry matter digestibility was significantly greater on sludge-treated areas than control areas for cherry leaves and twigs, brambles, and panic grass (Table 9). Panic grass showed the greatest increase in IVDMD (a 26% increase) on sludge-treated areas during the summer. For fall samples, brambles had the greatest increase (a 13% increase) in IVDMD on sludge-treated areas than control areas.

Cell Wall Constituents

Cell wall constituents were significantly lower on sludge-treated areas than controls for panic grass, and fall samples of jack pine twigs and brambles (Table 10).

Table 8. Comparisons of ash (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	4.46	0.19	5.13	0.76	$P > 0.100$
	Cherry twigs	2.99	0.10	3.36	0.19	$P > 0.100$
	Jack pine leaves	1.87	0.14	1.75	0.03	$P > 0.100$
	Jack pine twigs	2.05	0.12	1.83	0.07	$P \leq 0.050$
	Brambles	5.06	0.23	5.37	0.12	$P > 0.100$
	Orange-hawkweed	10.38	0.31	10.94	0.51	$P > 0.100$
	Sedge	5.28	0.25	5.89	0.22	$P \leq 0.100$
	Panic grass	3.93	0.07	3.64	0.17	$P > 0.100$
Fall						
	Cherry twigs	2.89	0.11	3.15	0.13	$P > 0.100$
	Jack pine leaves	1.96	0.01	2.12	0.04	$P \leq 0.050$
	Jack pine twigs	1.70	0.02	1.75	0.06	$P > 0.100$
	Brambles	2.49	0.12	2.42	0.08	$P > 0.100$

Table 9. Comparisons of *in vitro* dry mater digestibility (%) of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	59.50	3.08	47.95	3.07	$P \leq 0.100$
	Cherry twigs	32.07	0.84	28.33	0.65	$P \leq 0.050$
	Jack pine leaves	37.36	0.90	35.19	1.62	$P \geq 0.100$
	Jack pine twigs	40.39	1.76	35.59	0.89	$P > 0.100$
	Brambles	40.39	1.12	34.78	1.23	$P \leq 0.050$
	Orange-hawkweed	54.50	1.96	54.37	2.21	$P \geq 0.100$
	Sedge	39.20	3.24	39.22	2.93	$P > 0.100$
	Panic grass	47.95	0.95	38.19	2.54	$P \leq 0.010$
Fall						
	Cherry twigs	29.67	1.09	26.71	0.71	$P \leq 0.100$
	Jack pine leaves	31.74	0.55	31.94	0.41	$P \geq 0.100$
	Jack pine twigs	35.58	0.75	34.12	0.64	$P > 0.100$
	Brambles	30.62	0.69	27.02	1.63	$P \leq 0.100$

Table 10. Comparisons of cell-wall constituents (CWC%) and cell-soluble material (CSM%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	$\bar{X}$ CWC	$\bar{X}$ CSM	SE	$\bar{X}$ CWC	$\bar{X}$ CSM	SE	Probability
Summer								
	Cherry leaves	28.48	71.52	2.44	31.41	68.59	3.19	$P < 0.100$
	Cherry twigs	66.25	33.75	0.92	65.65	34.35	2.56	$P < 0.100$
	Jack pine leaves	45.56	54.44	1.00	50.06	49.94	2.48	$P < 0.100$
	Jack pine twigs	52.06	47.94	1.13	54.09	45.91	0.86	$P < 0.100$
	Brambles	44.04	55.96	1.47	42.89	57.11	1.28	$P < 0.100$
	Orange-hawkweed	34.08	65.92	1.31	35.99	64.01	0.67	$P < 0.100$
	Sedge	69.71	30.29	0.91	71.91	28.10	0.98	$P < 0.100$
	Panic grass	71.59	28.41	1.13	77.08	22.92	0.53	$P \leq 0.005$
Fall	Cherry twigs	61.52	38.48	1.18	63.86	36.14	0.70	$P < 0.100$
	Jack pine leaves	36.77	63.24	1.45	36.96	63.04	0.52	$P < 0.100$
	Jack pine twigs	43.12	56.88	1.05	46.60	63.40	1.00	$P < 0.025$
	Brambles	59.70	40.30	0.75	62.33	37.67	0.88	$P < 0.050$

Cell Soluble Material

Summer samples of panic grass and fall samples of jack pine twigs and brambles showed significantly greater CSM contents on sludge-treated areas than control areas (Table 10).

Acid-Detergent Fiber

Cellulose and lignin content of vegetation, determined by the ADF analysis was consistantly lower on sludge-treated areas than controls for all plant species (Table 11). This general trend was observed in vegetation samples for both sampling periods. Significantly lower values were found in jack pine twigs, brambles, orange-hawkweed, sedge, and panic grass for summer samples. Brambles were also significantly lower in ADF on sludge-treated areas than controls during the fall.

Orange-hawkweed and brambles showed the greatest change in ADF content with sludge application for the summer and fall respectively. Acid-detergent fiber values for orange-hawkweed and fall bramble samples were 15% and 7% lower on sludge-treated areas respectively.

Hemicellulose

Fall jack pine twig samples were the only species and part to show significantly lower hemicellulose content on sludge-treated areas than control areas. Orange-hawkweed

Table 11. Comparisons of acid-detergent fiber (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	19.49	1.16	24.53	2.31	$P > 0.100$
	Cherry twigs	56.11	0.78	56.26	0.88	$P > 0.100$
	Jack pine leaves	36.26	1.61	41.05	3.25	$P > 0.100$
	Jack pine twigs	44.01	0.67	46.18	0.55	$P \leq 0.100$
	Brambles	32.63	1.41	35.08	1.41	$P \leq 0.025$
	Orange-hawkweed	28.67	0.78	33.02	0.75	$P \leq 0.005$
	Sedge	40.52	0.59	43.58	0.60	$P \leq 0.100$
	Panic grass	39.88	0.57	45.60	0.91	$P \leq 0.005$
Fall						
	Cherry twigs	52.47	0.88	55.78	1.16	$P > 0.100$
	Jack pine leaves	29.40	0.27	30.01	0.63	$P > 0.100$
	Jack pine twigs	36.21	0.73	37.49	1.30	$P > 0.100$
	Brambles	48.72	0.51	52.24	1.38	$P \leq 0.100$

and bramble (summer and fall) samples had significantly greater hemicellulose values on control areas than sludge-treated sites (Table 12).

Acid-Detergent Lignin

Acid-detergent lignin content was consistantly lower on sludge-treated areas than controls for all species except sedge (Table 13). Summer species and parts that showed significantly lower ADL content on sludge-treated areas were: jack pine twigs, brambles, and cherry twigs. Brambles also showed significantly lower ADL content on sludge-treated areas than control areas during the fall. This species had the greatest decrease in ADL content with sludge-treatment for summer and fall (48% and 10% respectively).

Cellulose

All herbaceous plant species collected showed significantly lower cellulose content on sludge-treated areas than control areas (Table 14). Both panic grass and orange-hawkweed showed the greatest change in cellulose content with sludge application. Cellulose values were 16% lower on sludge-treated areas for both species.

Elemental Analysis

The results of statistical analysis of element contents in plant samples for sludge-treated and control

Table 12. Comparisons of hemicellulose (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	8.99	2.41	6.88	1.43	$P > 0.100$
	Cherry twigs	10.14	0.94	9.42	2.20	$P > 0.100$
	Jack pine leaves	9.30	1.47	12.20	3.03	$P > 0.100$
	Jack pine twigs	7.86	0.99	7.94	0.80	$P > 0.100$
	Brambles	11.41	0.78	7.81	0.50	$P \leq 0.005$
	Orange-hawkweed	5.41	0.85	3.33	0.58	$P \leq 0.025$
	Sedge	29.19	1.11	23.33	0.58	$P \geq 0.100$
	Panic grass	31.63	0.94	31.47	0.84	$P > 0.100$
Fall						
	Cherry twigs	9.05	0.92	8.09	1.09	$P > 0.100$
	Jack pine leaves	7.37	1.36	6.95	0.35	$P > 0.100$
	Jack pine twigs	7.36	0.32	9.11	1.08	$P \leq 0.100$
	Brambles	10.98	0.53	9.42	0.38	$P \leq 0.005$

Table 13. Comparisons of acid-detergent lignin (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	7.99	0.82	11.24	1.16	$P > 0.100$
	Cherry twigs	21.12	0.85	26.78	1.87	$P \leq 0.100$
	Jack pine leaves	15.33	1.06	16.32	0.59	$P \geq 0.100$
	Jack pine twigs	21.58	0.32	22.63	0.60	$P \leq 0.005$
	Brambles	7.35	0.55	11.60	1.48	$P \leq 0.100$
	Orange-hawkweed	8.49	0.65	9.12	0.47	$P \geq 0.100$
	Sedge	7.29	0.77	5.76	0.67	$P > 0.100$
	Panic grass	5.61	0.18	5.80	0.17	$P > 0.100$
Fall						
	Cherry twigs	27.39	1.00	29.84	1.87	$P > 0.100$
	Jack pine leaves	12.57	0.39	12.84	0.41	$P > 0.100$
	Jack pine twigs	17.80	0.62	18.59	0.31	$P > 0.100$
	Brambles	15.39	0.20	16.91	0.61	$P \leq 0.100$

Table 14. Comparisons of cellulose (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	11.51	0.40	13.30	1.31	$P > 0.100$
	Cherry twigs	34.99	0.73	29.48	1.80	$P > 0.100$
	Jack pine leaves	20.93	0.80	21.54	0.52	$P > 0.100$
	Jack pine twigs	22.44	0.64	23.39	0.36	$P > 0.100$
	Brambles	24.78	1.20	23.48	1.97	$P > 0.100$
	Orange-hawkweed	20.18	0.31	23.50	0.63	$P \leq 0.005$
	Sedge	33.22	0.56	37.60	0.66	$P \leq 0.005$
	Panic grass	34.28	0.48	39.81	0.93	$P \leq 0.005$
Fall						
	Cherry twigs	25.08	0.49	25.94	0.35	$P > 0.100$
	Jack pine leaves	16.82	0.36	17.17	0.37	$P > 0.100$
	Jack pine twigs	18.40	0.40	18.91	1.22	$P > 0.100$
	Brambles	33.32	0.60	35.99	0.58	$P \leq 0.025$

areas collected in 1980 are presented in Tables 15 through 27. Panic grass and brambles (summer and fall) assimilated significantly higher concentrations for the most elements on sludge-treated areas. Statistical analysis of summer data showed woody species and parts (cherries, jack pine, and brambles) accumulated significantly greater metal concentrations on sludge-treated areas than controls for an average of 2 elements per species and part. Orange-hawkweed had significantly greater concentrations for 4 of the selected metals on sludge-treated areas. Potassium was the only element significantly greater in sedge on sludge-treated sites. Panic grass accumulated the most elements during the summer. This species showed significantly greater concentrations for 11 of the 13 elements on sludge-treated areas than controls.

Analysis of fall samples indicated that brambles assimilated the most elements on sludge-treated sites. From summer to fall this species accumulated significantly greater concentrations of 6 additional elements on sludge-treated areas than controls. Cadmium was the only element with significantly greater concentrations on sludge-treated areas than controls in cherry twig and jack pine leaf samples. Nickel was the only element in jack pine twig samples with significantly greater concentrations on sludge-treated areas.

Table 15. Comparisons of zinc (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	25.15	1.73	18.65	0.97	$P = 0.008$
	Cherry twigs	44.02	3.23	48.97	3.32	$P > 0.100$
	Jack pine leaves	45.57	1.75	43.20	2.49	$P > 0.100$
	Jack pine twigs	56.18	0.88	50.28	4.34	$P > 0.100$
	Brambles	65.60	4.13	53.20	5.25	$P = 0.082$
	Orange-hawkweed	154.33	12.42	114.71	22.24	$P \leq 0.050$
	Sedge	60.22	3.67	53.03	4.11	$P \geq 0.100$
	Panic grass	30.98	1.92	14.78	0.75	$P < 0.001$
Fall						
	Cherry twigs	55.89	4.51	51.87	7.82	$P > 0.100$
	Jack pine leaves	51.74	3.75	56.60	3.95	$P > 0.100$
	Jack pine twigs	67.81	2.93	151.09	79.91	$P > 0.100$
	Brambles	78.31	6.93	56.69	3.37	$P = 0.017$

Table 16. Comparisons of lead (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	4.14	0.22	5.63	0.49	$P = 0.019$
	Cherry twigs	2.01	0.33	2.33	0.58	$P > 0.100$
	Jack pine leaves	1.96	0.56	0.93	0.25	$P > 0.100$
	Jack pine twigs	2.04	0.17	1.41	0.42	$P > 0.100$
	Brambles	5.45	0.38	6.49	0.44	$P = 0.091$
	Orange-hawkweed	18.12	5.25	10.61	0.93	$P > 0.100$
	Sedge	3.79	0.33	9.10	3.56	$P \leq 0.025$
	Panic grass	4.32	0.50	3.15	0.30	$P \equiv 0.060$
Fall						
	Cherry twigs	5.35	0.60	4.16	0.52	$P > 0.100$
	Jack pine leaves	4.03	0.49	3.86	0.51	$P > 0.100$
	Jack pine twigs	8.86	4.04	4.76	0.77	$P > 0.100$
	Brambles	5.52	0.70	3.38	0.56	$P = 0.033$

Table 17. Comparisons of chromium (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	1.08	0.09	1.74	0.31	$P = 0.072$
	Cherry twigs	0.74	0.07	1.04	0.14	$P = 0.090$
	Jack pine leaves	1.20	0.18	0.72	0.12	$P > 0.100$
	Jack pine twigs	0.91	0.11	0.79	0.27	$P > 0.100$
	Brambles	1.50	0.15	1.47	0.09	$P > 0.100$
	Orange-hawkweed	5.84	1.97	2.23	0.29	$P \leq 0.050$
	Sedge	0.41	0.12	0.41	0.09	$P \geq 0.100$
	Panic grass	0.76	0.09	0.47	0.08	$P = 0.028$
Fall						
	Cherry twigs	2.29	0.18	2.17	0.27	$P > 0.100$
	Jack pine leaves	1.95	0.06	1.63	0.20	$P > 0.100$
	Jack pine twigs	38.27	35.95	1.54	0.24	$P > 0.100$
	Brambles	2.29	0.22	1.45	0.19	$P = 0.011$

Table 18. Comparisons of cadmium (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	0.18	0.04	0.24	0.06	$P > 0.100$
	Cherry twigs	0.62	0.17	0.80	0.27	$P > 0.100$
	Jack pine leaves	0.33	0.06	0.43	0.20	$P > 0.100$
	Jack pine twigs	0.55	0.03	0.48	0.20	$P > 0.100$
	Brambles	1.07	0.09	0.68	0.09	$P = 0.007$
	Orange-hawkweed	1.59	0.38	0.73	0.13	$P = 0.050$
	Sedge	0.43	0.06	0.63	0.15	$P > 0.100$
	Panic grass	0.29	0.03	0.21	0.05	$P > 0.100$
Fall						
	Cherry twigs	0.51	0.09	0.25	0.04	$P = 0.019$
	Jack pine leaves	0.45	0.08	0.24	0.04	$P = 0.048$
	Jack pine twigs	0.74	0.06	0.91	0.18	$P > 0.100$
	Brambles	1.26	0.12	0.83	0.09	$P = 0.014$

Table 19. Comparisons of magnesium (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	6553	200	5661	200	$P = 0.011$
	Cherry twigs	7265	300	7026	700	$P > 0.100$
	Jack pine leaves	6258	300	4882	200	$P = 0.002$
	Jack pine twigs	6907	200	5522	500	$P = 0.030$
	Brambles	5416	100	5859	400	$P > 0.100$
	Orange-hawkweed	7728	1200	9854	800	$P > 0.100$
	Sedge	8529	700	7063	900	$P > 0.100$
	Panic grass	7572	190	5673	318	$P < 0.001$
Fall						
	Cherry twigs	2583	200	1904	100	$P = 0.009$
	Jack pine leaves	1850	200	1831	200	$P > 0.100$
	Jack pine twigs	2238	100	2072	100	$P > 0.100$
	Brambles	3157	200	2328	100	$P = 0.005$

Table 20. Comparisons of potassium (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	17050	300	19150	800	$P = 0.096$
	Cherry twigs	11430	1000	9218	600	$P = 0.084$
	Jack pine leaves	7107	500	6750	200	$P > 0.100$
	Jack pine twigs	10947	700	8620	900	$P = 0.077$
	Brambles	14594	1700	19455	2500	$P > 0.100$
	Orange-hawkweed	25522	2500	26200	2700	$P > 0.100$
	Sedge	15778	900	13098	1100	$P = 0.087$
	Panic grass	13844	1300	8703	600	$P = 0.002$
Fall						
	Cherry twigs	5617	400	4336	300	$P = 0.030$
	Jack pine leaves	5457	100	6116	300	$P = 0.035$
	Jack pine twigs	5810	200	5893	300	$P > 0.100$
	Brambles	5363	400	4473	300	$P = 0.068$

Table 21. Comparisons of manganese (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	676	95	904	39	$P = 0.051$
	Cherry twigs	292	54	416	51	$P > 0.100$
	Jack pine leaves	231	27	270	24	$P > 0.100$
	Jack pine twigs	238	24	227	35	$P > 0.100$
	Brambles	1294	98	1444	103	$P > 0.100$
	Orange-hawkweed	913	36	1242	193	$P > 0.100$
	Sedge	338	48	606	77	$P = 0.009$
	Panic grass	244	32	133	13	$P = 0.005$
Fall						
	Cherry twigs	273	35	283	10	$P > 0.100$
	Jack pine leaves	385	64	423	56	$P > 0.100$
	Jack pine twigs	286	33	332	30	$P > 0.100$
	Brambles	446	36	610	52	$P = 0.020$

Table 22. Comparisons of aluminum (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	52.63	10.37	65.87	2.34	$P > 0.100$
	Cherry twigs	12.75	2.09	13.63	1.47	$P > 0.100$
	Jack pine leaves	241.17	16.78	392.00	13.93	$P > 0.001$
	Jack pine twigs	172.17	10.36	238.50	25.36	$P = 0.036$
	Brambles	93.54	7.12	156.14	17.07	$P = 0.004$
	Orange-hawkweed	467.44	172.35	374.56	64.64	$P > 0.100$
	Sedge	75.73	7.92	121.47	19.95	$P = 0.049$
	Panic grass	86.27	9.32	90.80	5.29	$P > 0.100$
Fall						
	Cherry twigs	22.14	2.92	25.91	5.74	$P > 0.100$
	Jack pine leaves	390.33	41.68	636.00	57.34	$P = 0.003$
	Jack pine twigs	218.67	11.98	259.00	17.73	$P = 0.078$
	Brambles	43.64	6.41	31.25	1.77	$P = 0.098$

Table 23. Comparisons of copper (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	2.20	0.20	1.80	0.10	$P > 0.100$
	Cherry twigs	2.71	0.38	6.44	4.31	$P > 0.100$
	Jack pine leaves	2.01	0.25	1.63	0.09	$P > 0.100$
	Jack pine twigs	1.66	0.08	1.48	0.10	$P > 0.100$
	Brambles	2.99	0.14	2.30	0.12	$P = 0.001$
	Orange-hawkweed	9.63	2.37	3.82	0.39	$P \leq 0.025$
	Sedge	2.51	0.19	3.98	2.26	$P \geq 0.100$
	Panic grass	2.27	0.21	0.97	0.07	$P < 0.001$
Fall						
	Cherry twigs	2.18	0.21	8.29	6.53	$P > 0.001$
	Jack pine leaves	1.89	0.37	2.00	0.43	$P > 0.100$
	Jack pine twigs	1.79	0.15	2.64	0.59	$P > 0.100$
	Brambles	3.19	0.41	1.78	0.23	$P = 0.011$

Table 24. Comparisons of sodium (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	107.70	7.67	142.83	6.67	P = 0.006
	Cherry twigs	82.57	11.00	105.03	6.51	P > 0.100
	Jack pine leaves	27.30	6.26	38.62	4.37	P > 0.100
	Jack pine twigs	30.79	8.63	29.05	4.64	P > 0.100
	Brambles	124.00	6.92	104.38	10.92	P > 0.100
	Orange-hawkweed	167.22	11.20	156.88	15.66	P > 0.100
	Sedge	46.77	2.78	47.28	3.62	P > 0.100
	Panic grass	46.69	4.61	36.94	1.38	P = 0.060
Fall						
	Cherry twigs	78.84	16.37	90.44	29.82	P > 0.100
	Jack pine leaves	50.68	12.23	70.77	13.05	P > 0.100
	Jack pine twigs	76.53	14.94	103.64	20.39	P > 0.100
	Brambles	78.54	10.35	55.44	10.30	P > 0.100

Table 25. Comparisons of nickel (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	1.77	0.04	2.06	0.23	$P > 0.100$
	Cherry twigs	1.53	0.07	1.15	0.03	$P < 0.001$
	Jack pine leaves	1.76	0.12	1.63	0.09	$P > 0.100$
	Jack pine twigs	1.81	0.04	1.76	0.26	$P > 0.100$
	Brambles	1.94	0.13	1.94	0.12	$P > 0.100$
	Orange-hawkweed	5.44	0.52	3.74	0.46	$P = 0.026$
	Sedge	1.50	0.08	1.24	0.19	$P > 0.100$
	Panic grass	1.26	0.08	0.69	0.04	$P < 0.001$
Fall						
	Cherry twigs	1.28	0.10	2.39	1.40	$P > 0.100$
	Jack pine leaves	1.55	0.15	1.26	0.13	$P > 0.100$
	Jack pine twigs	2.31	0.20	1.72	0.19	$P = 0.049$
	Brambles	2.43	0.23	0.98	0.04	$P < 0.001$

Table 26. Comparisons of iron (ppm) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\bar{X}$	SE	$\bar{X}$	SE	
Summer						
	Cherry leaves	53.93	16.61	77.02	9.73	$P > 0.100$
	Cherry twigs	15.80	5.14	18.74	3.70	$P > 0.100$
	Jack pine leaves	123.88	44.43	51.08	5.53	$P \leq 0.100$
	Jack pine twigs	115.38	12.40	75.55	28.60	$P \geq 0.100$
	Brambles	145.22	17.97	95.00	12.45	$P = 0.035$
	Orange-hawkweed	1364.22	529.71	264.63	62.30	$P \leq 0.050$
	Sedge	96.81	11.79	77.61	11.79	$P \geq 0.100$
	Panic grass	167.17	19.36	77.22	4.42	$P < 0.001$
Fall						
	Cherry twigs	38.54	3.92	34.51	3.11	$P > 0.100$
	Jack pine leaves	50.66	7.77	67.97	10.97	$P > 0.100$
	Jack pine twigs	77.54	10.88	93.66	11.17	$P > 0.100$
	Brambles	53.06	6.58	26.00	3.17	$P = 0.003$

Table 27. Comparisons of calcium (%) content of vegetation from sludge-treated and control areas for samples collected during summer and fall, 1980.

Sample period	Species	Sludge-treated		Control		Probability
		$\overline{X}$	SE	$\overline{X}$	SE	
Summer						
	Cherry leaves	0.76	0.04	1.05	0.06	$P = 0.002$
	Cherry twigs	0.57	0.11	0.61	0.03	$P > 0.100$
	Jack pine leaves	0.13	0.01	0.15	0.01	$P > 0.100$
	Jack pine twigs	0.11	0.01	0.10	0.01	$P > 0.100$
	Brambles	0.77	0.07	0.77	0.08	$P > 0.100$
	Orange-hawkweed	0.99	0.04	1.05	0.14	$P > 0.100$
	Sedge	0.23	0.02	0.22	0.02	$P > 0.100$
	Panic grass	0.19	0.01	0.13	0.01	$P = 0.001$
Fall						
	Cherry twigs	0.54	0.05	0.58	0.07	$P > 0.100$
	Jack pine leaves	0.19	0.05	0.18	0.01	$P > 0.100$
	Jack pine twigs	0.10	0.004	0.14	0.01	$P = 0.002$
	Brambles	0.43	0.03	0.48	0.03	$P > 0.100$

Season-Treatment Interactions

Significant interactions between seasons and treatment effects on all chemical analyses are shown in Table 28. The magnitude of the effects of sludge application and season varied among the 4 plant species sampled during both seasons. Brambles showed significant interactions between seasons and treatments for the most elements and nutrients in which analyses were conducted.

In Vitro Dry Matter Digestibility-Fiber Constituents and Cell Soluble Material Correlations

Correlations for plant species on sludge-treated areas showed there was not a close relationship between all fiber constituents and CSM and IVDMD for any 1 species (Table 29). A strong correlation, however, was determined in jack pine twigs for hemicellulose and lignin to IVDMD. Orange-hawkweed also showed a strong relationship between IVDMD and cellulose and CSM. A strong relationship was also determined in sedge for CSM as well as lignin content Correlation for fall cherry twig samples showed a strong relationship between all fiber constituents and IVDMD, however, not with CSM.

Table 28. F-values of significant interactions between treatments and seasons of element and nutrient contents of vegetation samples.

Species	Elements and nutrients									
	Iron	Calcium	Nickel	Chromium	Lead	Aluminum	Magnesium	Potassium	EE	ADF
Cherry twigs										9.440*
Jack pine leaves	5.168*							3.060*		
Jack pine twigs	3.138*	6.721*					6.636%	5.451*		
Brambles			22.959*	5.928*	8.914*	13.705*	7.072*	3.407*	22.464*	

*Denotes significant differences at 0.10.

Table 29. Simple correlation coefficients between *in vitro* dry matter digestibility and fiber constituents and cell-soluble material.

Species	Sludge-treated				Control			
	Hemi[a]	Cell[b]	Lign[c]	CSM[d]	Hemi	Cell	Lign	CSM
	Summer							
Cherry leaves	0.51	-0.10	-0.33	-0.28	-0.48	-0.92**	-0.50	0.78*
Cherry twigs	-0.44	-0.05	0.61	-0.07	0.67	0.62	-0.59	-0.59
Jack pine leaves	-0.72	0.35	0.49	0.25	0.38	-0.63	-0.47	-0.25
Jack pine twigs	0.79*	0.24	-0.90**	-0.48	0.13	0.24	-0.64	0.01
Brambles	-0.37	0.43	-0.17	-0.09	-0.47	-0.02	0.15	-0.06
Orange-hawkweed	0.81**	0.43	0.02	-0.63*	-0.57	-0.61	-0.62	0.78*
Sedge	-0.13	0.03	-0.20	0.31	-0.28	-0.15	-0.66*	0.65*
Panic grass	0.07	0.13	0.39	-0.22	0.05	-0.25	-0.24	0.44
	Fall							
Cherry twigs	C.17	-0.40	-0.47	0.43	0.64*	0.90**	-0.85**	0.13
Jack pine leaves	-0.29	-0.74*	0.33	0.37	-0.01	-0.38	-0.18	0.41
Jack pine twigs	-0.04	0.04	-0.44	0.36	0.16	-0.20	0.02	0.06
Brambles	0.20	-0.52	0.35	0.18	0.55	-0.50	-0.91**	0.73

* significant at 0.05
**significant at 0.01

[a]Hemicellulose
[b]Cellulose
[c]Lignin
[d]Cell soluble material

DISCUSSION

Annual Productivity

The application of additional nutrients by inorganic and organic fertilizers to agricultural crops and forest lands has been documented by many authors to increase annual productivity (Sopper and Kardos 1973, Leaf *et al*. 1975, Bayoumi and Smith 1976, Hinesly *et al*. 1979). The significant increase in total annual productivity (Table 3) which occurred in this study as a result of sludge application parallels what these other researchers found.

Hahn *et al*. (unpubl. data) notes that spray irrigating, anaerobically digested, domestic sludge to pasture grasses significantly increased yields. Sopper and Kardos (1973) observed a similar response of increased annual production of an old field irrigated with municipal wastewater. They noted that with irrigation, productivity increased an average of 201% annually over a 10-year period. Red pine (*Pinus resinosa*) plots were also irrigated with wastewater in Sopper and Kardos' (1973) project and annual productivity monitored. They noted that with irrigation both the diameter and height of red pine increased.

Results from these projects support the findings of this study, that the application of organic fertilizers increased the productivity of numerous vegetation species.

The positive responses of various vegetation species to organic fertilizers has also been produced with inorganic fertilizers (Thomas et al. 1963, Bayoumi and Smith 1976). These authors documented that the application of nitrogen fertilizers increased forage production of both herbaceous and woody species.

The response of pin cherries to fertilization and heavy cutting has been documented by Auchmoody (1979). He stated that pin cherries regenerate heavily after a disturbance, such as cutting or fire but that many seeds may remain dormant in the soil for years. Auchmoody (1979) noted, however, seeds may be stimulated to germinate with an application of nitrogen as low as 56 kg/ha. Because the addressed study area was clear-cut and then treated with sludge which contained the equivalent of 481.5 kg/ha of nitrogen this would be expected to stimulate cherry germination and production. The clear-cutting in combination with sludge application would thus cause significantly greater annual productivity on sludge-treated areas. Another factor which may have contributed to the significant increase in pin cherry production is the high annual productivity and nutrient accumulation pin cherry normally exhibits (Marks 1974, Covington and Aber 1980).

Safford and Filip (1974) noted that with the fertilization of pin cherry the proportion and absolute amount of nutrients shifted from an even distribution among species in an unfertilized stand to a high proportion of pin cherry. They also documented that with fertilization 4 years after clear-cutting, *Rubus* spp. as well as pin cherries tended to dominate the stand in above-ground biomass and number of seedlings. Woodyard (1982) noted this same response with sludge application to the jack pine clear-cut of this study.

Since sludge application did increase production, it is possible that the initial effects of application are advantageous to wildlife (increased quantity of vegetation) but the long term effects may be detrimental. Because the nutrients contained in sludge are accelerating the production of plants they are also contributing to accelerating the maturation of those plants. Therefore, although plants fertilized with sludge may provide more quality vegetation for food and cover initially, the amount of time these areas will be beneficial to wildlife may be short-lived as vegetation structure changes. The preliminary findings of West *et al*. (1981) who monitored small mammal and herbivore use of sludge-treated areas support this hypothesis.

Crude Protein

From the data obtained it is evident that a single application of non-industrial municipal sludge did improve the nutritional quality of most wildlife forage species. The degree of nutritive quality improvement varied by plant species and season.

Because protein is a principle component of an animal's soft structures, a constant and adequate amount is required in the diet to support the animal's growth and reproduction (Maynard *et al*. 1979). The protein requirements of an animal, however, will vary with species and age. Murphy and Coates (1966) documented that forage protein content may be the most critical nutrient on some ranges and may account for low production and physical development observed in white-tailed deer (*Odocoileus virginianus*). They noted that body weights and antler development of yearlings and adult male white-tailed deer were drastically retarded by a diet of 7% protein. This same effect on white-tailed deer subsisting on protein-poor forages has been noted by other researchers (Einarsen 1946, French *et al*. 1956, McEwen *et al*. 1957, Smith *et al*. 1975).

Because of the nitrogen contained in sludge and its' application in this study to an early successional site with nutrient-poor soil, the nitrogen was readily assimilated by the vegetation. With this nitrogen influx, none of the plant species on sludge-treated areas had CP levels below the minimum requirement of 7% required by white-tailed deer. However, on control areas, 42% of the plant species of both seasons exhibited CP levels less than 7%.

Because of the sludge-induced increase in CP content and production of all plant species, wildlife species, such as white-tailed deer may choose to use sludge-treated vegetation more heavily than unsludged. Sludge-treated areas will thus provide more cover and better quality of forage for wildlife. Woodyard (1982) documented that the percentage of browsed stems for cherries and brambles was significantly greater ($P < 0.01$) on sludge-treated areas than controls on this study site. These results suggest that wildlife use was greater on sludge-treated areas possibly because of the increase in the quantity and quality of vegetation. Results from other studies support the finding that wildlife species do select areas where plant quantity and quality are increased with fertilization (Leaf et al. 1975, Dressler and Wood 1976, Barrett 1979).

Since cherries are known to accumulate nutrients readily and retain these primarily in the leaves and twigs (Safford and Filip 1974), these species showed greater CP levels than other plant species during both seasons. This corresponds with cherries' ability to assimilate high nitrogen levels.

It has been documented by Safford and Filip (1974) that *Rubus* spp. may also (like pin cherry) accumulate nutrients readily. This ability may enable *Rubus* spp. to dominate a stand in total biomass after fertilization. This was evident since brambles showed a greater increase in CP content on sludge-treated areas than control areas in the fall.

Phosphorus

Phosphorus has 3 basic functions in an organism; 1) structural, 2) a central role in energy transformation, and 3) a component of the nucleoproteins and cytoplasm in cells (Maynard *et al*. 1979). The ability of an organism to meet its phosphorus requirements will depend on the amount contained in the soil available for plant assimilation. The application of 571.4 kg/ha of phosphorus from sludge application provided plants with additional nutrients for plant accumulation. The amount of phosphorus accumulated by vegetation, however, may have resulted from: 1) the phosphorus content of the sludge, 2) the amount and chemical form of phosphorus available on the site prior to sludge application, 3) the speed at which different plant species grow and assimilate nutrients, and 4) root depths of various species.

As stated by Sommers (1977a), phosphorus concentrations in sewage sludge may equal or exceed the amount of nitrogen present. Because the phosphorus content in the sludge was slightly higher than the total nitrogen, the phosphorus content of this sludge was considered average. Some plant species accumulated significantly greater concentrations on sludge-treated areas than control areas.

Brockway et al. (1979) noted that irrigating vegetation with wastewater caused an increase in the level of phosphorus in vegetation. However, he attributed this increase to applying wastewater to a site already low in phosphorus. As stated earlier, the soil on the site was a nutrient-deficient sandy soil which may have been the reason vegetation accumulated phosphorus so readily.

From the results of summer analyses, only the herbaceous species accumulated significantly greater concentrations of phosphorus on sludge-treated areas than controls (Table 6). This response may be attributed to herbaceous species having a shallower root system than woody species and thus being capable of assimilating nutrients in the surface soil layers faster. Because the nutrients contained in the sludge will only enter the surface soil layers by decomposition and leaching resulting from percolating rainfall (Brockway 1979), the movement of phosphorus may be limited by weather and climate. As shown in Figure 2, the amount of precipitation during the summer sampling period (mid-July to mid-August) was well below average. This lack of rainfall may have contributed to the low mobility of phosphorus. Because phosphorus was restricted to the upper soil layers, only species with shallow root systems (such as herbaceous species) could assimilate significant levels.

Analysis of fall samples showed that all woody species had significantly greater phosphorus levels on sludge-treated areas than controls (Table 6). This positive response of phosphorus accumulation in the fall and not in summer may also be attributed to the amount of rainfall. Figure 2 shows that precipitation during the fall (September through November) was much greater than during the summer. This increase in precipitation may have caused phosphorus to be leached into deeper soil layers making it available to plants with a deep root system (such as woody species).

As documented by Short et al. (1966), the phosphorus content in a variety of vegetation samples has been related to protein content. This same type of response was observed in this study with most species. Those plant species which showed a significant increase in phosphorus, as a result of sludge-treatment, also showed an increase in CP (Table 5). However, all species which displayed a significant increase in CP did not show a significant rise in phosphorus. This response could be attributed to the sludge containing a relatively high concentration of nitrogen in relation to phosphorus (Sopper and Kardos 1973).

Because of the important functions phosphorus plays in an organism, adequate dietary supplies are essential. As discussed, sludge application did increase phosphorus content of a few plant species; was sludge application, however, necessary to increase the phosphorus content of vegetation to meet dietary needs of wildlife species?

Ullrey (pers. comm.) stated that weaned white-tailed deer fawns require a minimum of 0.28% (2300ppm - dry matter basis) phosphorus when the diet contains 0.45% (4500ppm) calcium for growth, skeletal, and antler development (calcium:phosphorus ratios will be discussed later). The results of this study indicate that only 25% of the summer plant species and parts on control areas met these requirements. Sludge-treated areas, however, showed adequate phosphorus levels for 63% of the plant species and parts. None of the fall plant species on sludge-treated or control areas had phosphorus levels of at least 0.28%. These results indicate that sludge application may increase normally low phosphorus levels to meet the dietary requirements of wildlife species, such as the white-tailed deer.

Ether Extract

Fats in the diet of an animal are essential for: 1) providing 2.25 times the metabolizable energy as proteins and carbohydrates (also serve as an energy source to plants), 2) aiding in the palatability of forage, 3) aiding in carrying the fat soluble vitamins, and 4) supplying essential fatty acids. Because of these factors, EE is an important parameter to assess when evaluating the nutritional quality of forages. In interpreting EE data, however, it should be realized that ether, in addition to extracting lipids also extracts chlorophyll, xanthophyll, carotene, waxes, and other substances. Therefore, the EE content of forages should not be referred to solely as fat (Maynard et al. 1979).

As the results of this project indicate, EE content was not consistantly greater on either sludge-treated or control areas. This inconsistancy may have been produced by the level of 1 nutrient affecting the relative amount of another nutrient in a plant. If a plant has a higher relative amount of other chemical constituents (nitrogen and phosphorus) then the relative amount of EE will decline without an actual change in amount. Therefore, the relative amounts of EE would not be expected to increase with sludge application because of the accumulation of nitrogen and phosphorus into the cell contents. Results of the chemical analysis support this conclusion since species on control areas showed a trend of higher EE content.

Ash

The ash content of vegetation samples comprised very little of the total composition (<11%). This chemical constituent is composed of all of the inorganic elements present in a sample and tells nothing about the specific elements present. Because each inorganic element comprises a minute part of the total plant composition any increase in concentrations would have to be large to produce a significant increase in ash content. Therefore, increases in ash content due to sludge application would not necessarily be expected. Any trends in increased element contents due to sludge application therefore, should be addressed to individual element analyses.

In vitro Dry Matter Digestibility-Fiber Constituents-Cell Soluble Material

Digestion coefficients are not constant for a given forage species. They may be influenced by several factors including chemical composition of the forage species, stage of maturity, and site conditions. The relationship between IVDMD and fiber constituent levels is important when attempting to evaluate the nutritional quality of a forage species. By determining the fiber constituent content and the level of digestibility of forages, researchers will be given an indication of how well each fiber component is used by an animal.

By comparing the results of IVDMD trials and individual fiber constituent levels it is evident that there was not a lot of correlation between these parameters (Table 29). This may be explained since vegetation on sludge-treated areas were able to assimilate additional nutrients from the sludge thus increasing the nutrient content of plant cells while lowering some fiber levels. Therefore, high nutrient contents in combination with lower levels of some fiber constituents might have masked any relationship between digestibility and fiber levels. On control plots, however, there were more significant relationships between IVDMD and the fiber constituents of individual plant species. This may be explained by fewer nutrients being available on control areas thus leaving other factors such as fiber levels, to exert more of an effect on digestibility levels. This was especially evident in the correlation for fall cherry twigs.

Even though there were not a lot of significant relationships between individual fiber constituent levels and IVDMD, results indicate that species (cherries, brambles, and panic grass) which showed higher IVDMD did have lower levels of some fiber constituents (CWC, ADF, ADL, and cellulose). Each species, however, did not consistently show significantly lower levels for each fiber constituent.

The plant species which showed significantly higher IVDMD values and lower lignin levels on sludge-treated areas had lignin contents which composed a small percentage of the total CWC (lignin values ranging from

5.6-7.9%). Even though summer cherry twigs and fall bramble samples contained relatively high lignin levels on sludge treated sites (21% and 15% respectively), this accounted for a small percentage of the total CWC. For summer cherry twig samples, lignin comprised only 32% of the total CWC. The lignin content of fall brambles accounted for 25% of the total CWC. Summer brambles also displayed significantly higher IVDMD and lower lignin levels on sludge-treated areas. These results may be attributed to these species exhibiting an active amount of growth.
It has been noted by Kozlowski and Keller (1968) that vegetation which is actively growing usually has a higher nutritional plane than dormant vegetation. This may be attributed to nutrients being assimilated into the plant cells during production. Therefore, if additional nutrients are available (such as nitrogen in sludge) to plants they will be accumulated thus increasing the nutrient content (CP) of vegetation (Cook and Harris 1950). This type of response was noticed on sludge-treated areas for cherries and brambles. These species showed an increase in both production and higher nutrient content (CP and phosphorus). Because of these high nutrient levels, fiber constituents (ADF and ADL) were depressed and thus lignification which may impair the digestibility of these species was delayed. According to VanSoest (1975) lignin must compose at least

40% of the total CWC for the digestion of CWC to cease. Lignin contents for cherry twigs and brambles were below this 40% level therefore, CWC was able to be partially digested.

Panic grass, another species which showed significantly higher IVDMD had lower levels of ADF, and cellulose with sludge-treatment. As with cherries and brambles, this response may be attributed to the ability of panic grass to assimilate nutrients. This was evident since panic grass showed significantly greater concentrations of CP, CSM, and phosphorus.

These results showed that species with greater CP and lower fiber levels had greater digestibility values, supporting the results of other researchers. Maynard et al. (1979) stated that forage species rich in protein will promote the *in vitro* microbial breakdown of fiber. Williams et al. (1953) noted that with a low protein diet an increase in starch intake will reduce the concentration and change the type of microorganisms in the rumen of sheep. On relatively high protein diets, however, no such effect occurred. Williams also stated that at all starch levels, protein addition increased the digestibility of dry matter.

Jack pine leaf and twig samples from both sampling periods did not show significantly higher IVDMD values on sludge-treated areas than on control areas. These results may be attributed to 3 factors: 1) jack pine samples still contained relatively high lignin content, even with sludge application (lignin composed an average of 34% of the total CWC for leaves and an average of 42% of the total for twigs), thus reducing CWC digestion, 2) the speed which jack pine accumulated nutrients was slow (significant CP values for both leaves and twigs only in the fall) thus, lower nutrient content could hinder digestibility, and 3) the presence of volatile or essential oils. These oils are often in high concentrations in coniferous species and may increase the ether extract content in vegetation (Nagy and Haufler 1980). According to Nagy et al. (1964), these oils are not metabolizable by animals and may prevent the digestion of forages by rumen microorganisms. Longhurst (1968) has reported that plants high in volatile oils are not consumed as frequently as those with lower concentrations. As shown in Table 7 jack pine (leaves and twigs) had the highest ether extract concentrations of all plant species analyzed. Thus, the presence of high levels of volatile oils in jack pine was likely and could have hindered IVDMD.

Elemental Analysis

Plant species which accumulated significantly greater concentrations of elements on sludge-treated areas had high levels of the sludge-borne ions, such as cadmium, zinc, magnesium, and copper. These species included cherry leaves, brambles (summer and fall), and panic grass. Sludge-borne elements may have been accumulated in these species because of: 1) structural and/or growth characteristics of the species, and/or 2) study site characteristics which may have promoted the assimilation of these elements by plant species.

The accumulation of sludge-borne elements into the foliage of cherries may be associated with the significant increase in cherry production produced by sludge-treatment. Svoboda *et al*. (1979) noted a similar response of river birch (*Betula nigra*) and silver maple (*Acer saccharinum*) accumulating sludge-borne elements in the foliage. The ability of herbaceous species to respond quickly to sludge application has been reported by Roth *et al*. (1979). This response may be explained by a structural characteristic of this plant group. Because herbaceous species have shallow root systems, elements contained in the sludge may be assimilated faster than by species with deeper root systems.

Another hypothesis for the significant accumulation of sludge-borne elements in the species mentioned is the site characteristics. It has been documented that the uptake of sludge-borne ions, such as cadmium, by plants is greater at lower soil pH, at lower soil organic matter, and at higher soil temperature (National Research Council 1980).

Descriptions of the soils on the study site, mentioned earlier, indicated that both types (Graycalm and Montcalm) are considered relatively acidic and contain little organic matter. These factors in combination with the growth characteristics of the plant species may be why sludge-borne elements were assimilated so readily on sludge-treated areas.

The calcium and phosphorus content in forage species are important since both elements play an integral part in an animal's metabolism (Maynard et al. 1979). Ullrey (pers. comm.) stated a minimum calcium-phosphorus ratio for weaned white-tailed deer fawns to be approximately 1.6:1, with the phosphorus content being 0.28%. Maynard et al. (1979) described an adequate ratio lying between 2:1 - 1:1. However, he stated that adequate nutrition may be met at ratios outside these limits if Vitamin D is in large supply.

Analysis for these 2 elements showed most plant species on sludge-treated areas had ratios near 2:1 - 1:1. Calcium-phosphorus ratios for most plant species on control areas were much wider than on sludge-treated areas primarily due to lack of available phosphorus on control areas.

All mineral elements, whether they are dietary essentials or not may be toxic if included in the diet at high levels. Cadmium and magnesium were the only 2 elements which had significantly greater concentrations on sludge-treated areas than controls which exceeded the maximum tolerance levels for domestic animals (National Research Council 1980).

Although cadmium concentrations were significantly greater in some plant species on sludge-treated areas, the maximum tolerance level (0.5 ppm) was also exceeded in vegetation on control areas. The plant species which showed the highest concentration of cadmium was orange-hawkweed. These results may be attributed to samples being contaminated by soil and/or sludge particles adherring to the vegetation upon collection. Because orange-hawkweed has a pubescent surface and is low-growing, contamination could have occurred resulting in elevated cadmium levels (as well as other elements). However, it has been noted that "leafy" vegetation (such as orange-hawkweed) usually contains the greatest concentrations (National Research Council 1980).

Ingestion of high concentrations of cadmium, especially where forages are low in zinc, iron, copper, calcium, and protein, will permit a greater absorption/toxicity of cadmium. The effects of cadmium toxicity may result in anemia, bone mineralization and kidney damage with "moderate" ingestion while higher levels can lead to death (National Research Council 1980). Because most plant species which accumulated cadmium concentration > 0.5 ppm did not have deficient levels (based on the dietary requirements of sheep) of the above mentioned elements or protein (National Research Council 1968), cadmium toxicity problems may not occur. The subject of heavy metal accumulation in animal tissues is the focus of ongoing research. Magnesium, like cadmium, also exhibited concentrations which exceed the maximum tolerance level (0.5-0.08%) (National Research Council 1980) on both sludge-treated and control areas (significantly greater on sludge-treated areas). As documented by the National Research Council (1980), however, toxicosis due to ingestion of natural forages has not been reported and does not appear likely. This may be attributed to adequate calcium-phosphorus ratios (1.5:1) which protect an animal from toxicosis. Because most plant species on sludge-treated areas (jack pine leaves - summer and fall, jack pine twigs fall, and sedge on control areas) had calcium-phosphorus ratios between 2:1 - 1:1, as mentioned earlier, magnesium toxicosis is unlikely.

Treatment-Season Interactions

The significance of conducting this analysis was to test if the response of different chemical constituents and elements to sludge application was significantly different between seasons. Thus, significant results would indicate that both factors (treatments and seasons) are dependent on one another in influencing nutrient and element levels.

Brambles showed significant interactions between treatments and seasons for 7 of the chemical analyses conducted (Table 28). Other species had less of a response, thus the effects of treatments and seasons must act more independently in affecting the nutrient quality of these species. These significant interactions between treatments and seasons indicate that there are various combinations from sludge-treatement and seasons which may influence the nutritive quality of vegetation.

SUMMARY AND RECOMMENDATIONS

The application of non-industrial municipal sludge increased plant productivity and the nutrient quality of a variety of wildlife forage species. These results may be attributed to the influx of nutrients into a nutrient poor forest soil.

The results of this study show an application of non-industrial municipal sludge, prior to the growing season, may increase the quantity and quality of vegetation for wildlife use. Plant species which will benefit the most from additional nutrients readily are species which characteristically assimilate nutrients readily and/or those which have shallow root systems. These species will benefit primarily because sludge-borne nutrients may be restricted to surface soil layers. The assimilation of these nutrients by plants will aid in maintaining wildlife forage species in a productive state of vigor which is attractive to wildlife. Because of the benefits received by applying sludge to appropriate forest lands, sludge application may serve as a method of habitat improvement for a diversity of wildlife species.

The emphasis of this study was to identify the potential of sludge application to forested areas as a disposal alternative and method of habitat improvement. Because sludge application increased production as well as nutrient quality, plant maturation may be accelerated and therefore, the benefits of sludge application short-lived. Information regarding the duration of sludge application benefits to various vegetation types and the accumulation of heavy metals in both forages and animal tissues should be the focus of future research. This will provide wildlife managers important data enabling them to maintain desirable forage species in a high nutritional status by sludge-treating various areas on a rotational basis.

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APPENDIX

Table 30. List of vascular plants on the study site.

Common name		Scientific name	Family
Jack pine	ap	Pinus banksiana, Lamb	Pinaceae
Bigtooth aspen		Populus grandidentata, Michx.	Salicaceae
Quaking aspen		Populus tremuloides, Michx.	Salicaceae
Red cedar		Juniperus virginiana, L.	Cupressaceae
White spruce		Picea glauca, (Moench) Voss.	Pinaceae
Black cherry		Prunus serotina, Ehrh.	Rosaceae
Choke cherry	(ap)	Prunus virginiana, L.	Roseceae
Pin cherry		Prunus pennsylvanica, L.	Rosaceae
Red maple		Acer rubrum, L.	Aceraceae
American red raspberry	(ap)	Rubus strigosus, Michx.	Rosaceae
Common blackberry		Rubus allegheniensis, Porter.	Rosaceae
Cinquefoil		Potentilla recta, L.	Rosaceae
Mapleleaf viburnum		Viburnum acerfolium, L.	Caprifoliaceae
Panic grass	bp	Panicum virgatum, L.	Gramineae
Sedge	b	Carex spp., L.	Cyperaceae
Red sorrel		Rumex Acetosella, L.	Polygonaceae
Smartweed		Polygonum spp., L.	Polygonaceae
Goldenrod		Solidago spp., L.	Compositae
Spotted knapweed		Centaurea maculosa, Lam.	Compositae
Bull thistle		Cirsium vulgare, (Savi) Tenore.	Compositae
Pussytoes		Antennaria neglecta, Green.	Compositae
Orange-hawkweed	b	Hieracium aurantiacum, L.	Compositae
Aster		Aster spp., L.	Compositae

Table 30. (cont'd.)

Common name	Scientific name	Family
Pokeweed	Phytolacca americana, L.	Phytolaccaceae
Tomato	Lycopersicon esculentum, Mill.	Solanaceae
Common mullein	Verbascum Thapsus, L.	Scrophulariaceae
Common plantain	Plantago major, L.	Plantaginaceae
St. John's-wort	Hypericum perforatum, L.	Hypericaceae

[a]denotes collection during the summer and fall

[b]denotes collection during just summer

[p]species collected for annual productivity analysis