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Evaluation of the Potential for Using Old-Field Vegetation as an Energy Feedstock: Biomass Yield, Chemical Composition, Environmental Concerns, and Economics

J. W. Johnston, Jr.

Environmental Sciences Division
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ABSTRACT

The major focus of current research on production of biomass for use as an energy feedstock involves selection of species and genotypes best suited for specific regions of the United States and development of crop management techniques that maximize biomass productivity while minimizing environmental impacts and economic costs (Cushman et al. 1988, Ranney et al. 1988). These efforts usually involve establishment and maintenance of monocultural systems. A major cost in these systems is the expense of establishing and maintaining monocultures.

When activities to maintain monocultures are abandoned, vegetation previously excluded by cultivation and the use of herbicides becomes established. The naturally occurring vegetation is self-sustaining and requires minimal inputs to produce significant quantities of biomass composed primarily of lignocellulosic materials suitable for use as energy feedstocks by the same processes being developed for conventionally produced lignocellulosic crops. Therefore, successional vegetation may offer the potential for production of cost-competitive lignocellulosic materials useful as energy feedstocks.

The productivity and chemical composition responses of vegetation from two old-field plant communities to harvesting frequency, fertilizer, and lime were measured over a 3-year interval. The two experimental sites, an abandoned soybean field (AS) and an abandoned pasture (AP) were studied. At the AS site, the effects of two harvest frequencies (1 or 2 harvests annually), two nitrogen fertilizer treatments (0 or 87 $kg \cdot ha^{-1} \cdot yr^{-1}$), and two phosphorous fertilizer treatments (0 or 111 $kg \cdot ha^{-1} \cdot yr^{-1}$) were determined. At the AP site, the effects of two harvest treatments (1 or 2 harvests annually), two fertilizer treatments (56:56:135 kg of $N:P:K \cdot ha^{-1} \cdot yr^{-1}$), and two lime treatments (0 or 4600 $kg \cdot ha^{-1} \cdot yr^{-1}$) were determined. At both sites, treatments were arranged in a randomized complete block 2 X 2 X 2 factorial experiment.

The results of this research effort indicated that old-field vegetation is: (1) sufficiently productive to provide significant quantities of energy feedstock; (2) chemically suitable as an energy feedstock; (3) environmentally benign with respect to impacts related to soil erosion and nutrient depletion; (4) relatively unresponsive to fertilizer and lime inputs; and (5) economically competitive with other biomass energy feedstock candidates. It was concluded that old-field vegetation offers a low input, low risk energy feedstock alternative.

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INTRODUCTION

The liquid fuel shortages predicted to begin in the United States during the next century prompted the Department of Energy (DOE) to begin research to identify alternative sources. The feasibility of using renewable energy resources was examined, and biomass was identified as a promising energy feedstock (OTA 1980). The ultimate success or failure in establishing a renewable, biomass energy industry depends upon a number of factors. The processes involved with feedstock production, conversion, and use must be economically competitive, environmentally benign, socially acceptable, and of potentially sufficient quantity to warrant the investment of research and capital outlay for its initiation.

Research has been initiated by both federal (DOE) and private research (e.g., Gas Research Institute) organizations to develop economically viable systems for production of energy feedstocks for conversion to fuels. The major focus of current research on biomass production involves selection of species and genotypes best suited for specific regions of the United States and development of crop management techniques that maximize biomass productivity while minimizing environmental impacts and economic costs (Cushman et al. 1988, Ranney et al. 1988). These efforts usually involve establishment and maintenance of monocultural systems. Major cost and risk factors associated with these systems include the expense and uncertainty of establishing and maintaining monocultures.

When activities to maintain monocultures are curtailed, weedy vegetation previously excluded by cultivation and herbicides quickly becomes established. The initial species are usually annuals which are followed in subsequent years by a sequence of vegetation types that follow general developmental patterns described as secondary plant succession (Oosting 1942). The sequence of vegetation types include annual herbs and grasses, perennial herbs and grasses, shrubs, early successional trees, and ultimately, if the site is not further disturbed, by climax forest species. The duration of any of the stages in the successional sequence depends to a large extent on the soil resources available on the site and the climatic conditions under which succession occurs.

The naturally occurring successional vegetation is self-sustaining and requires minimal inputs to produce significant quantities of biomass. This biomass is composed of the same chemical constituents as other herbaceous and woody crops and should therefore be suitable for conversion to liquid fuels by the same processes being developed for conventionally produced lignocellulosic crops. In addition, the successional vegetation offers other economic advantages related to its ability to be productive on lands considered marginal for agricultural uses, and the absence of production costs related to cultivation and establishment. Therefore, successional vegetation offers the potential for production of cost-competitive lignocellulosic materials useful as energy feedstocks.

Most of the research concerning successional vegetation can be categorized in one of two areas: (1) ecological research to study competitive relationships between species and changes in botanical composition during plant succession or (2) agricultural research for development of chemicals and cultural practices capable of excluding weed (early successional) species from crops. A significant body of information currently exists concerning the productivity responses of successional plant communities to various perturbations. Although this information can be useful for assessing the production potential of vegetation in mixed-species plant communities under a variety of environmental and climatic conditions, there is little information available concerning the sustained productivity of successional vegetation under different low-input management systems with repeated harvests (OTA 1980). Although some range management research has addressed the effects of grazing or haying on sustained productivity and yield of mixed-species plant communities, it is of limited value for assessing the usefulness of mixed-species vegetation as an energy feedstock because its emphasis on nutrient and palatability requirements that are unimportant for energy feedstock production technologies.

This report presents the results of an experiment performed to determine the suitability of vegetation in the old-field stage of succession as an energy feedstock. The research emphasis was placed on measurement of parameters that could affect the economics of using this vegetation as an energy feedstock. In this effort, the yield responses of two old-field plant communities differing in stage of succession to several management scenarios, including harvest frequency, fertilizer application, and soil pH adjustment by lime application, were studied to delineate the yields that could be expected from old-field vegetation grown for use as an energy feedstock material in low-input agricultural systems. The chemical composition of the organic components of the vegetation was analyzed to determine its suitability as an energy feedstock and to assess the proportion of the biomass that could be used and the remaining proportion for which alternative uses would be required. The inorganic chemical composition of the biomass and soil was analyzed so that issues related to soil nutrient depletion and mineral cycling with nutrient removal by harvesting could be assessed. A simple economic analysis compared the costs of producing successional vegetation as an energy feedstock with other energy crop alternatives.

PRODUCTIVITY OF SUCCESSIONAL VEGETATION

INTRODUCTION

Natural vegetation has been recognized as a potentially important source of feedstock material for biomass energy systems (OTA 1980; Lawson et al. 1984). In efforts to develop economically viable energy production systems using biomass feedstocks, productivity plays a dominant role. As in traditional agricultural systems, the yield of useful feedstock per unit of land area is an important parameter in formulas for determining the land base required for feedstock production, the costs for transporting the feedstock to conversion facilities, and the cost of inputs, such as fertilizers, required to achieve economically satisfactory productivities.

Secondary plant succession is the process that describes the changes that occur in plant communities following disturbances. Agricultural activities constitute a common disturbance that resets plant succession to year zero, from which changes in botanical composition occur. The early studies conducted to characterize plant succession were primarily descriptive, including those concerning the southeastern United States by Oosting (1942) and Quartermann (1957). In humid regions of the United States, the vegetation follows a sequence of vegetation types that progresses from annual grasses and herbs, to perennial grasses and herbs, shrubs, pioneer trees, and in cases where no disturbances occur over relatively long periods of time, a diverse assemblage of hardwood trees (Quartermann 1957). In general, the rate of progression and ultimate vegetation type that results from succession depends on the richness, in terms of resources such as available water and nutrients, of the site. Relatively rich sites generally exhibit rapid successional progression to climax forest types. Relatively poor sites exhibit slower progress and often are arrested at an intermediate successional stage, as occurs in savannah, prairie, or desert regions where water availability is limiting. Functional aspects have been emphasized in much of the plant succession research conducted following the initial descriptive studies (e.g., Keever 1950; Odum 1960; Mellinger and McNaughton 1975; Tilman 1987).

Information concerning aboveground productivity of biomass in early stages of old-field plant succession have been documented for a number of sites representing the major climatic regions of the United States. The productivity values presented were often based on standing crop measurements and can be interpreted as yield determinations at single points in time. Other studies focused upon estimation of net primary productivity, which is calculated from the summation of maximum standing crop measurements for each species present. Although useful in ecological studies, NPP measurements do not provide information concerning harvestable yield. None of these efforts included repeated harvests over several years, so their applicability for estimating the sustained yield potential of successional vegetation over time with repeated harvests is limited. Other efforts to characterize the productivity of mixed-species vegetation have included studies to determine the responses of range and pasture systems to different haying or grazing management scenarios (Baker 1976).

In this chapter the yield response of two successional communities to harvest frequency, fertilizer, and/or lime treatments are presented for 3 years of study. The yield data presented in this chapter will be used in the subsequent chapters for calculation of chemical yields and the economics of production.

MATERIALS AND METHODS

Experiments to determine the productivity of successional vegetation characteristic of idle or abandoned crop and pasture lands were established at two old-field sites in the Oak Ridge National Environmental Research Park, Roane County, Tennessee. Both sites are gently rolling (slope < 5%) alluvial bottomlands. The two sites, which are located approximately 300 m apart, differed in their recent history of use. The "abandoned pasture" site (AP) had been maintained as a grassland by occasional mowing (once every 3-5 years) for the past 40 years. The "abandoned soybean field" (AS) was similarly maintained prior to 1980. It was used for sorghum x sudangrass forage production in 1980, a winter wheat-soybean rotation from 1981 to 1984, and was fallow during 1985. Both sites were mowed without biomass removal in October 1985. The AP soil was a fine-loamy siliceous, thermic, aquic hapludult of the Whitwell series. The AS soil was a clayey, mixed thermic, aquic hapludult of the Wolftever series (P. A. Mays, personal communication).

The research areas on both sites were rectangular areas measuring 24.6 x 12.3 m. Thirty-two 9.6 m^2 plots were delineated in four blocks at each site. Soil samples were collected prior to the initiation of experimental treatments in order to determine the uniformity between and within sites. Because of the measured differences in soil chemical parameters (Table 1) and the differences in botanical composition between sites (Fig. 1), separate experiments tailored to the characteristics of each site were performed.

The experiment at the AS site tested the effects of nitrogen fertilization, phosphorous fertilization, and their combination on biomass yield and chemical composition at two harvest frequencies (one or two annual harvests). Treatments included a control, a nitrogen treatment, a phosphorous treatment, and a treatment that combined nitrogen and phosphorous applications.

The experiment at the AP site tested the effects of an N-P-K fertilizer, lime, and their combination, on biomass yield and chemical composition at two harvest frequencies (one or two annual harvests). Treatments included a control, a lime treatment, a fertilizer treatment, and a treatment that combined lime and fertilizer application.

The fertilizer treatments in both experiments were applied prior to the initiation of growth in the spring of 1987 and 1988, and immediately following the midsummer harvest in 1986, 1987, and 1988 at the rates shown in Table 2. Lime treatments were applied in midsummer in 1986 and in the spring of 1987 and 1988. Each treatment combination at both sites was tested at two cutting frequencies (a single fall cutting or a two-cut system including a midsummer and a fall cutting).

Experimental activities at both sites followed similar schedules (Table 3). Three soil samples were collected during the spring months

Table 1. Comparison of soil chemistry at the research sites prior to treatment applications[a]

Parameter	Site	
	Abandoned pasture	Abandoned soybean field
Organic matter (%)	2.4	2.7
pH	5.4	6.3
CEC ($meq \cdot g^{-1}$)	5.4	9.4
Phosphorous (ppm)	2.5	2.8
Potassium (ppm)	85.7	108.0
Magnesium (ppm)	94.9	251.6
Calcium (ppm)	563.8	1200.3

[a]Means for each parameter were significantly different ($P = 0.01$) based on analysis of variance (1,62 df).

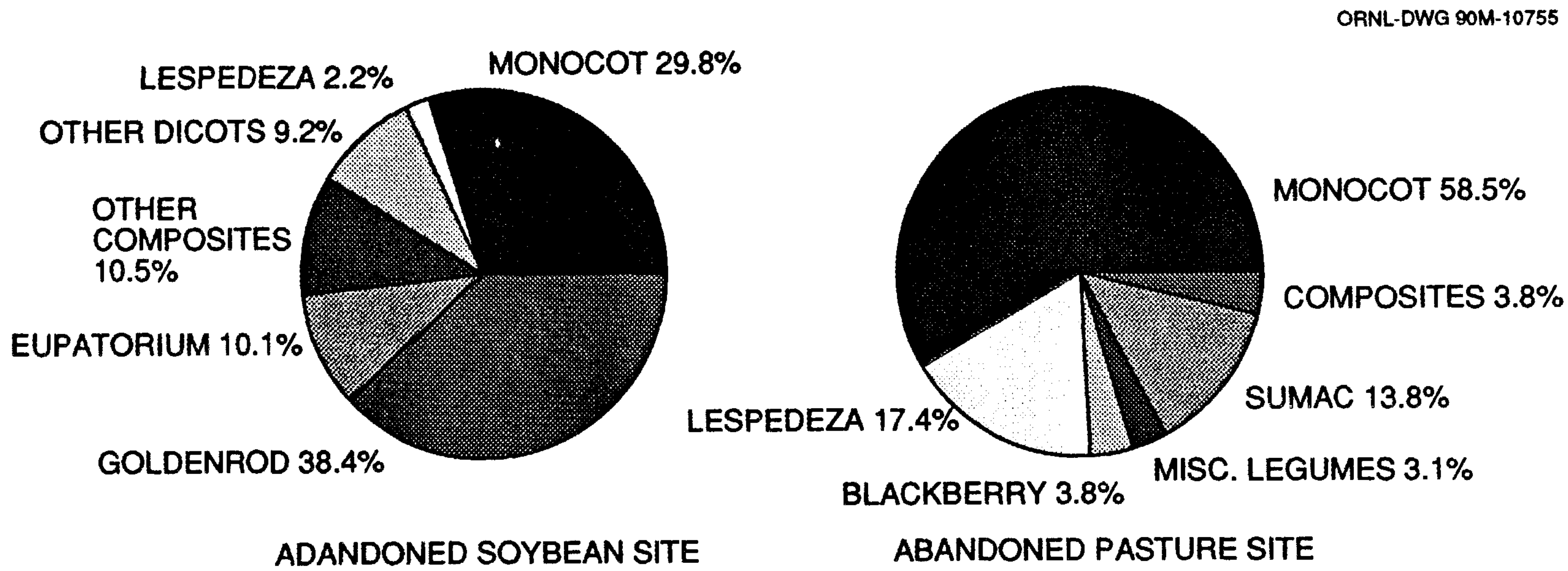

Fig. 1. Botanical composition of vegetation in two old-field successional plant communities prior to treatment applications.

Table 2. Fertilizer and lime application rates

Site/treatment	Elemental application rate ($kg \cdot ha^{-1} \cdot yr^{-1}$) Nitrogen[a]	Phosphorous[b]	Potassium[c]	Lime[d]
Abandoned Soybean Field				
Control	0	0	0	0
Nitrogen	87	0	0	0
Phosphorous	0	111	0	0
Nitrogen + Phosphorous	87	111	0	0
Abandoned Pasture				
Control	0	0	0	0
Lime	0	0	0	4600
N–P–K	56	56	135	0
Lime + N–P–K	56	56	135	4600

[a]Nitrogen applied was NH_4NO_3.
[b]Phosphorous applied was triple superphosphate [$Ca(H_2PO_4)_2$].
[c]Potassium applied was KCl.
[d]Lime applied was the high calcium type (98% $CaCO_3$).

Table 3. Schedule of activities

Date	Activity
October 10, 1985	Plot area mowed; biomass not removed
May 14, 1986	Individual plots delineated
June 4, 1986	Soil samples collected
July 10–22, 1986	Pre-treatment harvest of twice yearly plots
July 25, 1986	Fertilizer and lime treatments applied
November 10–17, 1987	All plots harvested
March 10, 1987	Soil samples collected
April 10, 1987	Spring fertilizer application
June 23–July 1, 1987	Midsummer harvest
July 9, 1987	Midsummer fertilizer application
October 22–26, 1987	AS site harvest
November 9–16, 1987	AP site harvest
February 27, 1988	Soil samples collected
April 10, 1988	Spring fertilizer application
May 23, 1988	First periodic sample collection
July 7, 1988	Midsummer harvest
July 13, 1988	Midsummer fertilizer application
December 9, 1988	Final periodic sample collection
January 5, 1989	Final harvest (standing crop was not measured)

from the A-horizon of each plot, composited into one sample per plot, and analyzed by A&L Agricultural Laboratories (Memphis, TN) for nitrate-nitrogen (1987 and 1988 only); organic matter (%); pH; and phosphorous, potassium, calcium, and magnesium (each in ppm quantities).

Treatments were randomly assigned to plots by block. In July 1986, after the assignment of treatments but prior to their application, biomass in plots scheduled to be harvested twice annually was harvested, dried, weighed, and subjected to analysis of variance in order to obtain a measure of the variability between blocks and plots within blocks. This harvest represented the first of the two harvests for 1986. Fertilizer and lime treatments were applied two days thereafter. All plots were harvested in the fall of 1986. Activities during 1987 and 1988 included spring fertilizer and lime application; the midsummer harvest for those plots scheduled to be harvested twice annually; midsummer fertilizer application for all plots; and the fall harvest of all plots. In addition, 0.25 m^2 samples were collected at 2- to 4-week intervals from May through December 1988 in order to track the accrual and disappearance of biomass through the course of a growing season.

The yearly fertilizer and lime treatments were broadcast by hand. The fertilizer was applied in two equal applications (April and July, beginning in July 1986). Lime was applied once per year, in the spring, except for 1986 when it was applied in July. Harvests during 1986 and 1987 consisted of mowing a 1.1-m swath through the center of each plot scheduled for harvest. A gas-powered, sickle bar hedge trimmer was used to mow the plots during the July 1986 harvest. All subsequent harvests were accomplished with a Gravely two-wheeled tractor equipped with a 1.1-m sickle bar. The vegetation was cut to a height of 10 cm in all harvests. Harvested biomass in 1986 and 1987 was was sorted by species or species group (monocots, for instance), dried at 70°C in a forced air drying oven until weight stability was attained, and weighed. During 1988, the 0.25 m^2 samples collected at 2- to 4-week intervals were sorted, dried, and weighed. Analysis of variance techniques were used to identify significant treatment effects and interactions. A quadratic regression model was used to smooth the response curves for the periodic standing crop measurements in 1988. Areas of plots not sampled were mowed and the biomass was removed within two days after the sample was collected.

RESULTS

Initial Site Uniformity

Botanical composition and standing crop

The AS was in its second year of plant succession after crop cultivation during the initiation of this experiment. This was the successional stage transitional between primarily annual and primarily perennial vegetation types. The AS site was dominated by monocots and composites (Fig. 1). The monocots primarily included sedges, *Juncus* sp. and *Sisyrinchium* sp. Goldenrod (*Solidago* sp.) was the dominant composite, followed in importance by *Eupatorium* sp., *Erigeron* sp., and others. A number of non-composite dicots were also present, including *Hypericum* sp., *Calistegia* sp., *Verbena* sp., and *Solanum americanum*.

The AP site had been maintained as an unimproved grassland for over 40 years by occasional mowing. The site was dominated by perennial grasses, (*Festuca arundinacea*, *Andropogon virginicum*, *Panicum* sp., *Tridens* sp.) and other monocots (59%), *Rhus copalina* (14%), and *Lespedeza bicolor* (17%) (Fig. 1).

There were no significant differences of total standing crop for the treatment assignments in the initial harvest in 1986, prior to treatment applications, although there were significant block effects at both the AS and AP sites (Table 4). There were significant differences in botanical composition in the treatment assignments at the AS site. Monocot standing crop averaged 274 $kg \cdot ha^{-1}$ (33%) less in plots destined to receive the nitrogen treatments than in those destined not to receive nitrogen. Dicot standing crop averaged 300 $kg \cdot ha^{-1}$ (16%) more in plots destined to receive the phosphorous treatments than in those destined to receive no phosphorous. The lack of statistical significance for total standing crop indicated that these significant differences for monocots and dicots were more a factor of heterogeneity of botanical composition than differences in productive potential between the treatment assignments.

Table 4. Mean square and significance levels[a] for assessing plot uniformity prior to treatment applications

Source of variation	Degrees of freedom	Standing crop Total ($X10^{-4}$)	Monocot ($X10^{-4}$)	Dicot ($X10^{-4}$)
		Abandoned Soybean Field		
Block	3	26.02*	16.70*	21.78*
Nitrogen treatment (Ntrt)	1	1.60	29.92*	17.70
Phosphorous treatment (Ptrt)	1	30.94	0.19	35.99*
Ntrt × Ptrt	1	0.41	0.74	0.05
Error	9	6.62	3.59	4.27
		Abandoned Pasture Site		
Block	3	81.47*	26.02	38.89
Lime treatment (Ltrt)	1	13.84	1.64	5.94
Fertilizer treatment (Ftrt)	1	89.81	12.04	36.09
Ltrt × Ftrt	1	14.94	38.73	5.56
Error	9	18.99	23.78	11.69

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

There were no statistically significant differences for total standing crop or standing crop of monocots or dicots prior to treatment applications at the AP site (Table 4).

Soil chemical composition

The differences in management of the two sites prior to initiation of the experiment were evident by differences in soil chemistry collected during 1986 (Table 1). Organic matter, cation exchange capacity (CEC), and phosphorous, potassium, magnesium, and calcium concentrations were higher and soil acidity was lower in soils of the AS site, reflecting the effect of lime and fertilizer applications in support of the previous soybean-winter wheat rotation. Analysis of variance of the 1986 soil chemistry data indicated statistically significant (Table 5) differences in chemical composition between treatment plots for some of the chemical parameters from both the AS and AP sites. Examination of the means (Table 6) for these significant effects indicated relatively minor differences, which were interpreted, along with the analysis of standing crop data previously presented, to be of little or no consequence for the experimental perturbations that were to follow.

Productivity During 1986

Abandoned soybean field

Total yield at the AS site in 1986 averaged across all treatments was 3712 $kg \cdot ha^{-1}$, ranging from 3204 $kg \cdot ha^{-1}$ in control plots harvested once to 4082 $kg \cdot ha^{-1}$ in plots receiving nitrogen and phosphorous fertilizer and harvested once.

The effect of harvest frequency on total yield was not statistically significant, even though the harvest frequency effect was highly significant for most of the sorting categories that were summed for the calculation of total yield (Table 7). Yield in plots harvested twice in 1986 averaged 3635 $kg \cdot ha^{-1}$ versus yield of 3789 $kg \cdot ha^{-1}$ in plots harvested once during the Fall (Table 8). The effect of harvest frequency on both monocots and dicots was highly significant, but the directions of their responses were opposite, resulting in offsetting

Table 5. Mean square and significance levels[a] for assessing homogeneity of soil chemical composition prior to treatment applications in 1986

Source of variation	Degrees of freedom	Organic matter	CEC	Phosphorous	Potassium	Magnesium	Calcium	pH ([H+])
Abandoned Soybean Field								
		(X10²)	(X10¹)	(X10⁰)	(X10⁻¹)	(X10⁻¹)	(X10⁻¹)	(X10¹)
Block	3	17.44	3.56	13.25	2.28	17.74	19.25	1.30
Harvest frequency (Freq)	1	5.28	8.45	<0.01	1.25	13.61	13.57	0.02
Nitrogen treatment (Ntrt)	1	9.03	3.20	10.13	0.45	46.51	7.23	0.44
Phosphorous treatment (Ptrt)	1	0.03	6.05	0.13	17.11	9.11	4.03	0.66
Freq × Ntrt	1	7.03	1.80	55.13**	7.20	40.61	0.62	4.44
Freq × Ptrt	1	13.78	1.25	10.13	6.61	1.01	2.83	0.24
Ntrt × Ptrt	1	16.53*	5.00	8.00	7.81	0.63	8.42	0.34
Freq × Ntrt × Ptrt	1	5.28	3.20	2.00	6.61	0.11	1.00	2.18
Error	21	3.52	3.56	6.51	7.01	46.01	6.92	1.18
Abandoned Pasture Site								
		(X10¹)	(X10¹)	(X10⁰)	(X10⁻¹)	(X10⁻¹)	(X10⁻³)	(X10¹)
Block	3	7.73**	0.81	8.38**	12.25*	0.44	2.48	4.19
Harvest frequency (Freq)	1	0.15	5.00**	0.13	1.51	2.81	15.31**	18.10
Lime treatment (Ltrt)	1	0.03	0.11	1.13	1.51	3.20	0.05	1.07
Fertilizer treatment (Ftrt)	1	0.25	1.51	0.13	15.31*	11.25	0.01	9.62
Freq × Ltrt	1	0.38	0.31	10.13*	0.61	1.01	7.81*	49.70**
Freq × Ftrt	1	0.20	1.01	1.13	0.11	1.01	4.05	1.17
Ltrt × Ftrt	1	0.04	0.45	0.13	5.51	6.05	0.31	0.94
Freq × Ltrt × Ftrt	1	0.03	0.20	0.13	0.61	4.51	0.05	0.14
Error	21	0.56	0.52	1.52	2.71	3.31	1.42	5.23

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

Table 6. Soil chemistry means prior to treatment application for parameters that exhibited significant effects in analysis of variance tests[a]

Abandoned Soybean Site

Phosphorous (ppm)

Harvest frequency	Nitrogen Treatment 0	Nitrogen Treatment 1
1	6.0ab	7.5ab
2	8.6b	4.9a

$LSD_{0.05}$ = 2.7

Organic matter content (%)

Phosphorous treatment	Nitrogen Treatment 0	Nitrogen Treatment 1
0	2.7ab	2.7ab
1	2.5a	2.8b

$LSD_{0.05}$ = 0.20

Abandoned Pasture Site

Harvest frequency	Calcium (ppm)	CEC ($meq \cdot g^{-1}$)
1	586b	5.5b
2	542a	5.3a

Fertilizer treatment	Potassium (ppm)
0	84a
1	88b

Harvest frequency	Lime treatment 0	Lime treatment 1
	Phosphorous	
1	2.8ab	2.0ab
2	1.8a	3.3b
$LSD_{0.05}$ = 1.3		
	Calcium (ppm)	
1	603c	569bc
2	528a	556ab
$LSD_{0.05}$ = 39		
	pH	
1	5.5b	5.4ab
2	5.3a	5.4ab
$LSD_{0.05}$ = 0.08×10^{-7}([H+])		

[a]Means followed by the same letter for each soil parameter are not significantly different based on least significant differences.

Table 7. Mean square and significance levels[a] for the productivity responses of old-field vegetation to harvest frequency and fertilizer applications in 1986 in an abandoned soybean field

Source of variation	Degrees of freedom	Total	Monocot	Dicot	*Solidago* sp	*Aster pilosus*	*Eupatorium* sp	Misc. composites
		$(X10^{-4})$	$(X10^{-4})$	$(X10^{-4})$	$(X10^{-5})$	$(X10^{-4})$	$(X10^{-4})$	$(X10^{-4})$
Block	3	52.14	38.23	78.99	24.74*	1.16	5.08	65.34
Harvest frequency (Freq)	1	18.98	720.10**	972.88**	51.84**	21.43**	45.96**	410.29**
Nitrogen treatment (Ntrt)	1	43.69	15.09	110.13	1.10	2.48	0.84	41.36
Phosphorous treatment (Ptrt)	1	168.60	39.92	44.43	>0.01	0.57	0.17	74.81
Freq x Ntrt	1	25.87	0.61	18.52	2.10	2.48	0.84	4.56
Freq x Ptrt	1	0.02	1.38	1.71	4.71	0.57	0.17	23.32
Ntrt x Ptrt	1	7.39	1.06	14.05	1.39	2.50	0.08	1.82
Freq x Ntrt x Ptrt	1	30.31	24.13	0.35	0.64	2.50	0.08	16.74
Error	21	47.50	13.92	45.07	3.10	1.82	2.00	36.47

	Degrees of freedom	Misc Dicots	*Rubus* sp	*Oxalis* sp	*Hypericum* sp	*Convoluulus* sp	*Lespedeza* sp	*Datura stramonium*
		$(X10^{-4})$	$(X10^{-3})$	$(X10^{-2})$	$(X10^{-3})$	$(X10^{-3})$	$(X10^{-3})$	$(X10^{-4})$
Block	3	7.12	12.17	4.40	12.14	3.64	14.06	24.96
Harvest frequency (Freq)	1	22.73**	8.95	54.59**	6.09	27.02**	11.72	50.84*
Nitrogen treatment (Ntrt)	1	0.02	0.01	0.27	<0.01	0.47	0.40	36.97
Phosphorous treatment (Ptrt)	1	3.28	7.87	0.11	2.73	0.06	36.71*	2.73
Freq x Ntrt	1	0.04	1.92	0.27	2.34	0.47	8.03	36.97
Freq x Ptrt	1	2.43	7.54	0.11	9.54	0.06	25.49*	2.73
Ntrt x Ptrt	1	0.48	6.41	0.02	8.32	1.44	0.14	0.36
Freq x Ntrt x Ptrt	1	0.03	20.42	0.02	5.30	1.44	7.74	0.36
Error	21 2.70	7.65	1.72	5.70	2.06	5.51	10.78	

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

Table 8. Effect of harvest frequency on biomass yield ($kg \cdot ha^{-1}$) of old-field successional vegetation at the abandoned soybean site in 1986

Vegetative component	Harvest Frequency 1	Harvest Frequency 2	Statistical significance[a]
Total productivity	3789	3635	N.S.
Monocot productivity	581	1530	**
Dicot productivity	3207	2104	**
Solidago sp	1953	1148	**
Miscellaneous composites	828	516	**
Rubus sp	29	63	N.S.
Oxalis sp	0	26	**
Hypericum sp	67	95	N.S.
Convolvulus sp	0	58	**
Lespedeza bicolor	75	114	N.S.
Datura stromonium	0	252	*
Miscellaneous dicots	254	85	**

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

differences that explain the lack of significance for the harvest frequency effect on total yield. Monocot yield in the plots harvested twice during 1986 averaged 949 kg•ha^{-1} more than in plots harvested once (1530 kg•ha^{-1} vs 581 kg•ha^{-1}, respectively). Dicot yield in the plots harvested twice during 1986 averaged 1102 kg•ha^{-1} less than in plots harvested once (2105 kg•ha^{-1} vs 3207 kg•ha^{-1}, respectively). Monocots accounted for 15% of the harvested biomass in plots harvested once in 1986, compared to 42% in plots harvested twice. The contribution of *Solidago* to the total yield was reduced from 52% in the one-cut system to 32% in the two-cut system, primarily due to the lack of regrowth following the first harvest in the two-cut system. The other composites, *Eupatorium* sp., *Aster pilosus*, and *Erigeron* sp., exhibited similar changes in productivity. Their combined contribution to the total yield dropped from 22% in the one-cut system to 14% in the two-cut system.

Since there were no significant differences between treatment assignments prior to treatment applications, the differences in yield between the harvest frequency treatments in 1986 were due primarily to differences in regrowth following the midseason harvest. Regrowth averaged 34% of the total yield in plots harvested twice in 1986, totalling 1253 kg•ha^{-1}. Monocots constituted 66% of the total regrowth. *Solidago* contributed only 19% of the regrowth, averaging 233 kg•ha^{-1}.

The effects of nitrogen and phosphorous fertilizer applications were not statistically significant for total yield or any of the sorting categories at the AS site in 1986, except for a significant effect of phosphorous and phosphorous*harvest frequency interaction on *Lespedeza* yield (Table 7). In the treatment that combined two harvests without phosphorous fertilization, *Lespedeza* production averaged 153 kg•ha^{-1}, 2 to 3 times greater than the other treatment combinations. There were no significant nitrogen or phosphorous fertilizer effects or interactions on regrowth (Table 9).

It is interesting to note the pattern of occurrence of *Datura stramonium*, which occurred only as a regrowth component in plots receiving either phosphorous or nitrogen fertilizer. *Datura* yield ranged from an average of 0.0 kg•ha^{-1} in control plots to a maximum mean

Table 9. Mean square and significance levels[a] for the effects of lime and fertilizer on regrowth of old-field vegetation following a midsummer harvest in 1986

Source of variation	Degrees of freedom	Productivity Total	Monocot	Dicot
		Abandoned Soybean Field		
		($X10^{-4}$)	($X10^{-4}$)	($X10^{-3}$)
Block	3	8.43	8.18	7.91
Nitrogen treatment (Ntrt)	1	5.48	4.71	0.29
Phosphorous treatment (Ptrt)	1	12.42	32.89	48.90
Ntrt x Ptrt	1	1.76	11.14	40.39
Error	9	17.92	7.18	62.93
		Abandoned Pasture		
		($X10^{-5}$)	($X10^{-5}$)	($X10^{-3}$)
Block	3	3.11*	2.28	14.24**
Fertilizer treatment (Ftrt)	1	13.38**	11.51**	7.03
Lime treatment (Ltrt)	1	0.02	0.03	0.10
Ftrt x Ltrt	1	2.73	1.80	9.54*
Error	9	0.58	0.62	1.72

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

yield of 547 $kg{\cdot}ha^{-1}$ in plots receiving both nitrogen and phosphorous fertilizer. High block-to-block variability (absence in several plots, including the controls) was responsible for the lack of statistical significance for *Datura* yield. It is apparent that *Datura* seed are adapted for germination and rapid growth after disturbances, such as the mowing treatment in this experiment. *Datura* was a common weed when the AS site was used for soybean production.

Abandoned pasture

Total yield ranged from 3093 $kg{\cdot}ha^{-1}$ in control plots harvested once to 4958 $kg{\cdot}ha^{-1}$ in plots receiving both nitrogen and phosphorous fertilizer that were harvested twice. Total yield, as well as yield of several sorting categories, were significantly effected by harvest frequency, fertilizer, and lime in 1986 (Table 10). Plots harvested twice averaged approximately 30% more biomass production than those harvested once (Table 11). Yield of monocots and dicots was enhanced approximately 10% and 100%, respectively, in the two-cut system when compared with the one-cut system. Among the dicots, all of the sorting categories exhibited enhanced yield in two-cut treatments, ranging from 10X for the miscellaneous legumes and 5X for *Rubus* to 67% for *Lespedeza*. The enhancement for monocots was not statistically significant. *Andropogon*, a warm season grass, exhibited enhanced yield (60%) in the single-cut treatments. The effect of harvest frequency on dicot productivity at the AP site was opposite the effect at the AS site in 1986.

Fertilizer significantly enhanced yield by stimulating growth of the monocots (Table 11). The enhancement of total yield due to fertilizer application was 553 $kg{\cdot}ha^{-1}$, of which the monocots accounted for all but 3 $kg{\cdot}ha^{-1}$. The fertilizer treatment did not significantly affect yield of *Andropogon*, *Panicum*, or any of the dicot categories.

Lime application enhanced total yield 473 $kg{\cdot}ha^{-1}$, primarily by the effect on the legume component, which accounted for approximately half (211 $kg{\cdot}ha^{-1}$) of the lime treatment effect (Table 11). The effect of lime on the monocot component was not statistically significant,

Table 10. Mean square and significance levels[a] for the productivity responses of old field vegetation to harvest frequency, lime, and fertilizer applications in 1986 in an abandoned pasture

Source of variation	Degrees of freedom	Total	Monocot	Dicot	Total legumes	Misc. legumes	*Lespedesza* sp	*Rhus* sp
		$(X10^{-5})$	$(X10^{-5})$	$(X10^{-5})$	$(X10^{-4})$	$(X10^{-3})$	$(X10^{-4})$	$(X10^{-4})$
Block	1	15.47**	7.34*	2.60	38.85**	6.99*	48.47**	62.63**
Harvest frequency (Freq)	1	80.60**	7.61	38.68**	66.82**	66.08**	31.40*	60.25*
Lime treatment (Ltrt)	1	17.99	2.94	6.38*	35.56*	0.07	34.59*	3.28
Fertilizer treatment (Ftrt)	1	22.64**	24.26**	0.03	1.09	0.44	0.69	0.00
Freq x Ltrt	1	0.09	0.01	0.04	2.59	0.17	3.03	6.14
Freq x Ftrt	1	3.58	0.20	2.09	15.97	0.05	16.55	0.14
Ltrt x Ftrt	1	5.60	2.14	0.82	49.74**	2.71	57.36**	9.32
Freq x Ltrt x Ftrt	1	2.82	10.37*	2.38	0.38	2.74	1.30	18.49
Error	21	2.46	1.98	1.01	4.67	1.51	5.05	9.89

Source of variation	Degrees of freedom	Misc Composites	*Rubus* sp	Misc. dicots	*Andropogon* sp	*Panicum* sp	Misc. monocots
		$(X10^{-2})$	$(X10^{-3})$	$(X10^{-2})$	$(X10^{-3})$	$(X10^{-3})$	$(X10^{-5})$
Block	1	53.79	9.12*	10.22	10.05	12.84	6.91*
Harvest frequency (Freq)	1	70.19	83.73**	74.94**	51.87*	8.10	10.20*
Lime treatment (Ltrt)	1	32.37	1.23	0.15	23.86	1.03	1.76
Fertilizer treatment (Ftrt)	1	22.81	0.03	33.16**	17.61	6.35	22.63**
Freq x Ltrt	1	<0.01	0.38	7.21	<0.00	5.06	0.01
Freq x Ftrt	1	5.26	0.01	0.01	31.49	2.73	0.71
Ltrt x Ftrt	1	17.43	5.17	1.65	10.71	2.21	2.69
Freq x Ltrt x Ftrt	1	39.25	3.20	3.54	14.18	6.28	6.73
Error	21	26.74	2.12	3.53	8.35	5.46	1.83

[a]* = significant with >95% confidence; ** = significant with <99% confidence.

Table 11. Effect of harvest frequency, lime, and fertilizer on productivity ($kg \cdot ha^{-1}$) of old-field vegetation at the abandoned pasture site in 1986

Vegetation component	Harvest Frequency ($harvests \cdot year^{-1}$)			Fertilizer Treatment ($kg \cdot ha^{-1}$)			Lime Treatment ($kg \cdot ha^{-1}$)		
	1	2	Statistical significance[a]	0.0	56-56-135	Statistical significance[a]	0.0	4600	Statistical significance[a]
Total yield	3520	4555	**	3761	4314	**	3801	4274	*
Monocot yield	2798	3106	NS	2677	3227	**	2856	3048	NS
Panicum sp	96	128	NS	126	98	NS	117	106	NS
Andropogon sp	215	135	*	151	198	NS	148	202	NS
Miscellaneous	2487	2844	*	2399	2931	**	2591	2740	NS
Dicot yield	722	1449	**	1084	1086	NS	945	1226	*
Lespedeza sp	420	619	*	534	505	NS	415	623	NS
Misc. legumes	8	98	**	57	49	NS	52	54	NS
Rhus sp	154	429	*	292	291	NS	259	323	NS
Rubus sp	24	126	**	74	76	NS	81	69	NS
Composites	93	123	NS	99	116	NS	98	118	NS
Miscellaneous	23	54	**	29	49	**	39	38	NS

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

although the magnitude of the enhancement of production for monocots was 192 kg•ha^{-1}.

As in the AS experiment, the effects of harvest frequency at the AP site were also due to the difference of growth between the one-cut and the two-cut treatments after the midsummer harvest. Regrowth accounted for 34% of the total yield at the AP site, averaging 1362 kg•ha^{-1} across all treatments. NPK fertilizer significantly enhanced regrowth, primarily by enhancing the monocot component. Total regrowth averaged 1530 kg•ha^{-1} in plots receiving fertilizer compared with 994 kg•ha^{-1} in plots without fertilizer. The significant fertilizer × lime treatment interaction for dicot regrowth (Table 9) was due to a less than additive enhancement of productivity in plots receiving both lime and fertilizer (Table 12).

Productivity During 1987

Abandoned soybean field

Total annual yield in 1987 at the AS site averaged 5272 kg•ha^{-1} across all treatments, with a range from 6559 kg•ha^{-1} in plots receiving both nitrogen and phosphorous and a single harvest to 4153 kg•ha^{-1} in plots fertilized with nitrogen and harvested once (Table 13). On average, dicots accounted for 82% of the total yield.

The effect of harvest frequency was not significant for total yield, even though the harvest frequency effect for the monocot and dicot components was highly significant (Table 14). As in 1986, this was due to opposite effects of approximately equal magnitude (Table 15). Yield of monocots was 1013 kg•ha^{-1} greater in two-cut treatments than in one-cut treatments (1465 kg•ha^{-1} vs 452 kg•ha^{-1}, respectively). Yield of dicots was 1010 kg•ha^{-1} greater in the one-cut treatments than in the two-cut treatments (4774 kg•ha^{-1} vs 3764 kg•ha^{-1}, respectively). Within the composites group, the response of *Solidago* was different than the miscellaneous composite group that was primarily composed of annuals and biennials such as *Erigeron*, *Aster*, and *Carduus*. Yield of *Solidago* was reduced 2312 kg•ha^{-1} in the two-cut system, compared with the one-cut system. This reduction of *Solidago* was partially offset by the 1404

Table 12. Combined effect[a] of fertilizer and lime on regrowth ($kg \cdot ha^{-1}$) of dicots at the abandoned pasture in 1986

Lime Treatment ($kg \cdot ha^{-1}$)	Fertilizer Treatment ($kg \cdot ha^{-1}$ of N-P-K) 0-0-0	56-56-135
0	57.4a	148.2b
4600	101.2ab	94.2ab
LSD0.05 = 66.3		

[a]Means followed by different letters were not significantly different based on least significant differences test (P = 0.05)

Table 13. Response of old-field vegetation to harvest frequency, fertilizer, and lime in 1987

Abandoned Soybean Field

Harvest frequency	Fertilizer ($kg \cdot ha^{-1}$) Nitrogen treatment	Phosphorous treatment	Yield ($kg \cdot ha^{-1}$) Dicots	Monocots	Total
1	0	0	4609.0	492.4	5101.4
1	0	111	4283.4	807.7	5091.2
1	87	0	3905.1	247.6	4152.8
1	87	111	6298.7	260.1	6558.8
2	0	0	3394.1	1117.2	4511.3
2	0	111	3700.5	1842.8	5543.2
2	87	0	3840.3	1317.2	5157.5
2	87	111	4120.3	1582.0	5702.4

Abandoned Pasture Site

Harvest frequency	Fertilizer treatment ($kg \cdot ha^{-1}$)	Lime treatment ($kg \cdot ha^{-1}$)	Yield ($kg \cdot ha^{-1}$) Dicots	Monocots	Total
1	0-0-0	0	1070.2	1229.0	2299.2
1	0-0-0	4600	2571.3	1412.5	3983.8
1	56-56-135	0	2903.7	2436.3	5340.0
1	56-56-135	4600	3721.4	2927.9	6649.3
2	0-0-0	0	1108.9	891.8	2000.7
2	0-0-0	4600	1550.5	1121.9	2672.4
2	56-56-135	0	1350.7	1753.9	3104.6
2	56-56-135	4600	1939.2	2561.2	4500.4

Table 14. Mean square and significance levels[a] for the yield responses of old-field vegetation to harvest frequency and fertilizer in 1987 at an abandoned soybean field

Source of variation	Degrees of freedom	Total	Monocot	Dicot	*Solidago* sp	Misc. composites	Misc. legumes	*Lespedeza*	*Rubus* sp	Misc. dicots
		$(\times10^{-5})$	$(\times10^{-5})$	$(\times10^{-5})$	$(\times10^{-6})$	$(\times10^{-6})$	$(\times10^{-3})$	$(\times10^{-5})$	$(\times10^{-3})$	$(\times10^{-3})$
Block	3	19.53	2.32	14.59	1.34	0.41	6.58	16.44*	7.49	4.26
Harvest frequency (Freq)	1	0.05	84.84**	89.21*	41.08*	15.17*	24.75*	7.58	10.26	19.64
Nitrogen treatment (Ntrt)	1	7.37	2.98	19.71	2.80	0.02	1.17	2.40	0.12	15.32
Phosphorous treatment (Ptrt)	1	75.37*	9.83	30.77	4.07	2.36*	1.64	37.83*	2.21	54.67
Freq x Ntrt	1	0.66	2.08	0.40	2.21	0.91	0.40	1.84	0.28	8.61
Freq x Ptrt	1	2.77	1.69	8.79	0.44	0.93	0.68	9.41	44.55*	1.29
Ntrt x Ptrt	1	20.17	3.58	40.76	0.58	0.23	0.16	5.11	5.09	12.99
Freq x Ntrt x Ptrt	1	45.11	0.03	42.98	1.41	<0.01	0.03	7.50	0.76	0.03
Error	21	14.81	2.87	15.68	1.03	0.36	2.79	5.33	9.24	13.88

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

Table 15. Effect of harvest frequency, nitrogen fertilizer, and phosphorous fertilizer applications on biomass yield ($kg \cdot ha^{-1}$) of old-field vegetation at an abandoned soybean field in 1987

Vegetation component	Harvest Frequency (Harvest per year) 1	2	Statistical significance[a]	Nitrogen Treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$) 0.0	87.0	Statistical significance[a]	Phosphorous Treatment ($kg \cdot ha^{-1}$) 0.0	111.0	Statistical significance[a]
Total yield	5226	5229	NS	5062	5393	NS	4731	5724	*
Monocot yield	452	1465	**	1065	851	NS	794	1123	NS
Panicum sp	2	54	**	38	19	NS	12	45	*
Dicot yield	4774	3764	*	3997	4541	NS	3937	4600	NS
Solidago sp	2921	609	**	1489	2042	NS	1431	2100	NS
Misc. composites	715	2119	**	1382	1452	NS	1137	1697	*
Misc. legumes	0	58	**	34	24	NS	35	23	NS
Lespedeza sp	1031	785	NS	963	853	NS	1218	598	*
Rubus sp	30	66	NS	50	46	NS	57	40	NS
Misc. dicots	76	127	NS	79	124	NS	60	143	NS

[a] * = significant with >95% confidence; ** = significant with >99% confidence; NS = not significant.

kg•ha^{-1} yield stimulation for the miscellaneous composite group in the two-cut system. *Lespedeza*, a perennial legume, responded as the perennial *Solidago*, exhibiting a yield reduction of 246 kg•ha^{-1} in the two-cut system.

Phosphorous application had a statistically significant (Table 14) effect on total yield, enhancing total productivity 21% from 4731 kg•ha^{-1} in plots receiving no phosphorous fertilizer to 5724 kg•ha^{-1} in plots that received phosphorous fertilizer (Table 15). The phosphorous effect was not statistically significant for either monocots or dicots, although the direction of the phosphorous response was positive in both cases (329 kg•ha^{-1} and 663 kg•ha^{-1}, respectively). All dicots responded positively to phosphorous application except for the legumes. *Lespedeza* yield was reduced from 1218 kg•ha^{-1} without phosphorous fertilizer to 598 kg•ha^{-1} with phosphorous fertilizer.

Nitrogen application did not have a significant effect on total yield or yield of any of the vegetative components (Tables 14 and 15).

There was a statistically significant harvest frequency X phosphorous fertilizer interaction for yield of *Rubus*. Variability was very high (coefficient of variation = 199%). The interaction probably represented a Type I error (Snedecor and Cochran 1967) due to the relative rarity of *Rubus* occurrences.

The first harvest accounted for 76% of the annual yield of plots harvested twice in 1987, ranging from 3625 kg•ha^{-1} in plots receiving no nitrogen or phosphorous fertilizer to 4260 kg•ha^{-1} in plots receiving both nitrogen and phosphorous fertilizer (Table 16). There were no significant effects of nitrogen or phosphorous, or nitrogen X phosphorous interactions, for dicots or total yield (Table 17). However, the effect of phosphorous on monocot yield was statistically significant. Monocot yield averaged 526 kg•ha^{-1} greater (69%) in plots receiving phosphorous fertilizer than in those receiving no phosphorous fertilizer (Table 18). Although the effect of phosphorous fertilization on dicot yield was not significant, several of the components of dicot yield were significantly affected by phosphorous fertilization. Yield of the composites (sum of the *Solidago* and the miscellaneous group) was

Table 16. Standing crop (kg•ha^{-1}) of old-field vegetation at midseason of 1987

Treatment	Dicots	Monocots	Total
	Soybean Site		
Control	2816.4	808.9	3625.2
Nitrogen	3163.9	724.7	3888.7
Phosphorous	2640.7	1484.9	4125.7
Nitrogen + Phosphorous	3158.2	1101.3	4259.5
	Pasture Site		
Control	694.8	452.4	1147.2
Fertilizer	1261.8	1305.5	2567.3
Lime	1449.3	660.8	2110.1
Fertilizer + Lime	1330.8	1613.5	2944.2

Table 17. Mean square and significance levels[a] for the effects of nitrogen and phosphorous fertilizer on yield of old-field vegetation harvested twice annually from an abandoned soybean field in 1987

Source of variation	Degrees of freedom	Total	Monocot	Dicot	Goldenrod	Misc. composites	Black-berry	Lespedeza	Misc. legumes	Misc. dicots
Spring and Early Summer Biomass Harvested in July 1987										
		($\times10^{-5}$)	($\times10^{-5}$)	($\times10^{-5}$)	($\times10^{-5}$)	($\times10^{-5}$)	($\times10^{-4}$)	($\times10^{-5}$)	($\times10^{-3}$)	($\times10^{-3}$)
Block	3	5.55	4.84	14.99	3.67	1.51	2.40	7.11	11.46	5.58
Nitrogen treatment (Ntrt)	1	1.58	2.19	7.48	10.72	6.45	0.04	0.02	1.49	1.38
Phosphorous treatment (Ptrt)	1	7.59	11.08*	0.33	39.96*	27.69*	3.17	30.66*	2.21	17.07
Ntrt x Ptrt	1	0.17	0.90	0.29	3.12	1.28	0.46	0.39	0.06	4.96
Error	9	6.84	2.22	5.41	5.63	3.72	1.24	2.70	4.64	8.02
Regrowth in Late Summer and Fall Following the July 1987 Harvest										
			($\times10^{-4}$)	($\times10^{-4}$)	($\times10^{-4}$)	($\times10^{-3}$)	($\times10^{-1}$)	($\times10^{-4}$)		($\times10^{-2}$)
Block	3	1.12	11.47	0.72	3.28	3.36	1.74	4.39	-	2.09
Ntrt	1	1.67	16.57	<0.01	2.33	0.49	27.15	1.00	-	1.77
Ptrt	1	4.98	0.39	58.96*	95.18*	10.25**	1.73	9.94	-	1.11
Ntrt x Ptrt	1	1.28	2.60	3.84	8.71	0.10	0.61	0.93	-	2.12
Error	9	3.72	17.11	9.73	3.06	0.88	6.96	2.52	-	2.90

[a]* = significant with >95% confidence; ** = significant with >99% confidence.
[b]There was no regrowth for miscellaneous legumes.

Table 18. Mean yield response of old-field vegetation to phosphorous fertilizer at an abandoned soybean field in 1987

Vegetation component	Spring and Early Summer Yield ($kg \cdot ha^{-1}$) Rate ($kg \cdot ha^{-1} \cdot yr^{-1}$) 0	111	Statistical significance[a]	Regrowth Yield ($kg \cdot ha^{-1}$) Rate ($kg \cdot ha^{-1} \cdot yr^{-1}$) 0	111	Statistical significance[a]
Total yield	3757	4193	NS	1077	1430	NS
Monocot yield	767	1293	*	450	419	NS
Misc. monocots	747	1209	*	449	416	NS
Panicum	20	84	NS	1	3	NS
Dicot yield	2990	2899	NS	627	1011	*
Solidago	363	545	*	365	853	**
Misc. composites	1285	1934	*	29	80	**
Rubus	103	14	NS	8	6	NS
Lespedeza	1093	218	**	208	50	NS
Misc. legumes	70	47	NS	0	0	NS
Misc. dicots	75	141	NS	17	22	NS

[a]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

increased 831 kg•ha^{-1}, which off-set the 875 kg•ha^{-1} yield reduction for lespedeza caused by phosphorous fertilization (Table 18).

Total regrowth after the midseason harvest accounted for 34% of the annual total of the two-cut system and was not significantly affected by either nitrogen or phosphorous (Table 17) . Dicot yield was significantly increased by phosphorous application (Table 18), primarily due to increased yield of the composites (*Solidago* and the miscellaneous composites category). The increased yield due to the composites was partially offset by the negative effect (P=0.07) of phosphorous fertilizer on lespedeza yield, which declined from 208 kg•ha^{-1} without phosphorous to 50 kg•ha^{-1} with phosphorous fertilization.

Abandoned pasture site

Total annual productivity in 1987 at the AP site averaged 3819 kg•ha^{-1} across all treatments, with a range from 2001 kg•ha^{-1} in control plots harvested once to 6649 kg•ha^{-1} in plots receiving fertilizer and lime and a single harvest (Table 13). On average, dicots accounted for 54% of the total yield. The harvest frequency, fertilizer, and lime effects were statistically significant for total, monocot, and dicot yield (Table 19). In addition, the harvest frequency X fertilizer interaction was significant for dicot and total yield.

Yield from the one-cut system was greater than from the two-cut system for monocots (419 kg•ha^{-1}, 26%) and dicots (1080 kg•ha^{-1}, 73%). The effect of harvest frequency on monocots was primarily due to the greater yield of the miscellaneous monocot group in the one-cut system, compared to the two-cut system (1800 kg•ha^{-1} vs 1372 kg•ha^{-1}, respectively) (Table 20). *Panicum* exhibited significantly greater yield in the one-cut treatment, as opposed to the significantly lower yield of *Andropogon* in the one-cut treatments. The effect of harvest frequency on the dicots was primarily due to the greater (5.1X) production of the miscellaneous composites in the one-cut system (Table 20). *Rubus* and the miscellaneous legumes, two of the minor sorting categories, exhibited greater yield in treatments harvested twice annually (2.3X and 18.5X, respectively).

Table 19. Mean square and significance levels[a] for the yield responses of old-field vegetation to harvest frequency, lime, and fertilizer in 1987 at abandoned pasture

Source of variation	Degrees of freedom	Total yield	Monocot yield	Misc. monocots	*Panicum*	*Andropodon*	Dicot yield
		(X10^{-6})	(X10^{-6})	(X10^{-6})	(X10^{-3})	(X10^{-3})	(X10^{-6})
Block	3	0.02	0.08	0.08	15.78	13.82	0.15
Harvest frequency (Freq)	1	17.97**	1.41**	1.47**	33.93*	43.67*	9.32**
Fertilizer treatment (Ftrt)	1	37.31**	12.62**	13.42**	3.73	2.53	8.53**
Lime treatment (Ltrt)	1	12.81**	1.47**	1.28**	0.86	2.40	5.61**
Freq x Ftrt	1	3.85*	0.09	0.13	5.79	0.37	2.77*
Freq x Ltrt	1	0.43	0.07	0.02	0.18	13.68	0.83
Ftrt x Ltrt	1	0.06	0.39	0.20	2.42	15.54	0.14
Freq x Ftrt x Ltrt	1	0.60	0.04	0.40	2.86	2.07	0.34
Error	21	0.90	0.13	0.13	6.13	8.81	0.52

Source of variation	Degrees of freedom	Sumac	Misc. composites	Lespedeza	Misc. legumes	Black-berry	Misc. dicots
		(X10^{-4})	(X10^{-6})	(X10^{-5})	(X10^{-3})	(X10^{-3})	(X10^{-2})
Block	3	25.66*	0.44	8.72**	6.11*	1.55*	2.44
Harvest frequency (Freq)	1	0.26	13.08**	1.94	38.59**	4.02**	1.54
Fertilizer treatment (Ftrt)	1	22.27	2.56*	1.87	0.38	2.04*	7.06
Lime treatment (Ltrt)	1	0.01	1.02	16.47**	3.54	0.08	2.23
Freq x Ftrt	1	4.05	1.66	0.19	0.03	0.04	5.28
Freq x Ltrt	1	6.88	0.79	0.67	1.39	0.84	12.60
Ftrt x Ltrt	1	0.63	0.12	8.96*	5.01	1.16	10.38
Freq x Ftrt x Ltrt	1	6.85	0.27	0.70	7.18	0.03	0.36
Error	21	7.32	0.37	1.76	1.93	0.45	3.72

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

Table 20. Mean yield response (kg•ha^{-1}) of old-field vegetation from an abandoned pasture to harvest frequency, fertilizer, and lime in 1987

Vegetation component	Harvest Frequency (harvests•year^{-1}) 1	2	Statistical significance[a]	Fertilizer Treatment (kg•ha^{-1}•yr^{-1} of NPK) 0.0	56-56-135	Statistical significance[a]	Lime Treatment (kg•ha^{-1}•yr^{-1}) 0.0	4600	Statistical significance[a]
Total yield	4568	3070	**b	2739	4899	**b	3186	4452	**
Monocot yield	2001	1582	**	1164	2420	**	1578	2006	**
Panicum sp	146	81	*	124	103	NS	108	119	NS
Andropogon sp	55	129	*	101	83	NS	83	101	NS
Miscellaneous	1800	1372	**	939	2234	**	1386	1787	**
Dicot yield	2567	1487	**b	1575	2479c	*b	1608	2446	**
Lespedeza sp	601	756	NS	602*	755	NSc	452	906	**c
Misc. legumes	4	74	**	42	35	NS	28	49	NS
Rhus sp	289	271	NS	197	363	NS	278	281	NS
Rubus sp	18	41	**	21	37	*	31	28	NS
Composites	1635	322	**b	696	1262	*b	800	1158	NS
Misc. dicots	19	24	NS	17	26	NS	19	24	NS

[a]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.
[b]Significant harvest frequency x fertilizer interaction.
[c]Significant fertilizer x lime interaction.

Yield enhancement due to fertilizer application averaged 79% (Table 20). Monocot yield was doubled (108% increase) in treatments that included fertilizer application, from 1164 kg•ha^{-1} without fertilizer to 2479 kg•ha^{-1} with fertilizer. The fertilizer effect was due to the effect on the miscellaneous monocots. Panicum and Andropogon were not significantly affected by fertilizer application. Dicot yield in treatments that included fertilizer application was 58% greater than those receiving no fertilizer, primarily due to the response of the miscellaneous composites.

The harvest frequency X fertilizer interactions for total and dicot yield was due to the greater effect of fertilizer in the one-cut system than the two-cut system (Table 21).

Yield enhancement due to lime application averaged 1266 kg•ha^{-1} (40%). Monocot and dicot yields were increased 428 kg•ha^{-1} (27%) and 838 kg•ha^{-1} (52%), respectively (Table 20). The *Lespedeza* response to lime accounted for all of the yield enhancement due to lime enhancement among the dicots.

The combined effect of lime and fertilizer applications was less than additive for *Lespedeza* yield (Table 22). Lime application in the absence of fertilizer application enhanced *Lespedeza* yield 788 kg•ha^{-1} (4.8X); lime application in combination with fertilizer application enhanced *Lespedeza* yield only 119 kg•ha^{-1} (1.2X).

The first harvest accounted for 71% of the annual yield of plots harvested twice in 1987, ranging from 1147 kg•ha^{-1} in control plots to 2944 kg•ha^{-1} in plots receiving fertilizer and lime (Table 16). Both fertilizer and lime had significant effects on total and monocot yield (Table 23). Fertilizer application enhanced total, monocot, and miscellaneous monocot yields 1.7X, 2.6X, and 2.9X, respectively (Table 24). Lime application enhanced total, monocot, and miscellaneous monocot yields 1.4X, 1.3X, and 1.3X, respectively (Table 24). The effect of fertilizer or lime on total dicot yield from the July harvest was not significant (Table 23). Among the dicots, only the miscellaneous composites exhibited a significant fertilizer effect, and none of the dicots exhibited significant lime application effects (Table 24). Fertilizer application caused a doubling of yield of the

Table 21. Combined effect of harvest frequency and fertilizer treatment on yield ($kg \cdot ha^{-1}$) of miscellaneous dicots and total yield of successional vegetation in an abandoned pasture in 1987[a]

Harvest frequency	Fertilizer Treatment ($kg \cdot ha^{-1}$ of N-P-K) 0-0-0	56-56-135
	Total Dicots	
1	1821a	3313b
2	1330a	1645b
LSD0.05 = 753		
	Total Yield	
1	3142a,b	5995c
2	2337a	3802b
LSD0.05 = 985		

[a]Means followed by the same letter are not significantly different according to least significant differences ($P > 0.05$).

Table 22. Combined effect of fertilizer and lime on yield (kg•ha^{-1}) of *Lespedeza* at an abandoned pasture in 1987[a]

Lime treatment (kg•ha^{-1}•yr^{-1})	Fertilizer Treatmenta	
	0	1
0	208a	696b
4600	996b	815b
$LSD_{0.05}$ = 436		

[a]Means followed by the same letter were not significantly different based on least significance differences (P = 0.05).

Table 23. Mean square and significance levels[a] for the effects of fertilizer and lime on yield of old-field vegetation harvested twice annually from an abandoned pasture in 1987

Source of variation	Degrees of freedom	Total yield	Monocot yield	Misc. monocots	Panicum	Andropogon	Dicot yield	Rhus	Misc. composites	Lespedeza	Misc. legumes[b]	Rubus	Misc. dicots
Yield from Spring and Early Summer Growth													
		(x10^{-5})	(x10^{-5})	(x10^{-5})	(x10^{-3})		(x10^{-5})	(x10^{-4})	(x10^{-3})	(x10^{-5})	(x10^{-3})	(x10^{-2})	(x10^{-2})
Block	3	7.76	0.55	0.73	5.82	-	4.80	16.27	3.86	6.93	9.72	15.18*	0.76
Fertilizer treatment (Ftrt)	1	50.82**	32.61**	32.55**	0.05	-	2.01	0.94	19.99**	0.41	0.30	7.14	0.03
Lime treatment (Ltrt)	1	17.95**	2.67**	2.37**	0.89	-	6.78	0.61	0.15	5.03	4.69	7.81	2.77
Ftrt x Ltrt	1	3.43	0.10	0.15	0.47	-	4.70	1.98	0.04	9.23	12.11	2.64	2.19
Error	9	2.85	0.25	0.30	1.88	-	1.98	4.66	1.56	1.92	3.13	3.78	1.80
Regrowth from Late Summer and Fall													
		(x10^{-5})	(x10^{-5})	(x10^{-5})	(x10^{-2})	(x10^{-4})	(x10^{-4})	(x10^{-4})	(x10^{-5})	(x10^{-3})		(x10^{-0})	(x10^{-1})
Block	3	3.03	0.51	0.11	1.07	2.25	1.95	0.82	1.03	3.48	-	34.00*	0.64
Frt	1	4.59	2.46*	2.93**	0.11	0.24	0.33	0.90	0.06	0.02	-	0.48	1.79
Ltrt	1	5.30	2.71*	1.63*	<0.01	1.37	0.43	1.29	0.06	0.25	-	1.00	0.43
Ftrt x Ltrt	1	17.16	2.28*	1.15	3.47	1.45	6.93	1.01	3.84	10.97	-	14.24	1.42
Error	9	4.96	0.40	0.27	1.78	1.56	3.00	0.95	1.64	4.46	-	4.88	2.08

[a] * = significant with >95% confidence; ** = significant with >99% confidence.

[b] There was no regrowth of the miscellaneous legumes.

Table 24. Mean yield response of old-field vegetation to fertilizer and lime applications in July 1987 at an abandoned pasture

Vegetation component	Fertilizer Rate ($kg \cdot ha^{-1}$ of N-P-K)			Lime Rate ($kg \cdot ha^{-1}$)		
	0-0-0	56-56-135	Statistical Significance[a]	0	4600	Statistical sigificance[a]
Total yield	1629	2756	**	1857	2527	**
Monocot yield	557	1459	**	879	1137	**
Misc. monocots	486	1386	**	815	1058	*
Panicum	70	73	NS	64	79	NS
Andropogon	0	0	-	0	0	-
Dicot yield	1072	1296	NS	978	1390	NS
Rhus copalina	215	264	[illegible]	220	259	NS
Misc. composites	71	142	**	103	110	NS
Lespedeza	655	757	NS	529	883	NS
Misc. legumes	78	69	NS	56	91	NS
Rubus sp	31	45	NS	45	31	NS
Misc. dicots	21	20	NS	25	17	NS

[a]NS - not significant; * - significant with >95% confidence; ** - significant with >99% confidence.

miscellaneous dicots from 71 to 142 kg•ha^{-1}. There were no significant fertilizer X lime interactions for any of the sorting categories.

Total regrowth after the midsummer harvest accounted for 29% of the annual yield of plots harvested twice in 1987. Regrowth yields ranged from 537 kg•ha^{-1} in plots receiving fertilizer without lime to 1556 kg•ha^{-1} in plots receiving fertilizer and lime. There were no significant effects of fertilizer or lime on total regrowth or regrowth of any of the dicot categories (Table 23). Regrowth of the monocots was significantly enhanced by both fertilizer (55%) and lime (64%) treatments (Table 25). Both fertilizer and lime significantly enhanced monocot regrowth, but their combined effect resulted in yield enhancement averaging 509 kg•ha^{-1}, combined with the control treatment (Table 26). This constituted a 2.2X yield enhancement.

Incremental Changes in Standing Crop During Growth in 1988

Experimental objectives during 1988 were different from those of 1986 and 1987. Harvests for 1986 and 1987 were scheduled to accommodate what were assumed to be the best combinations of yield and nutrient retention on site. Therefore, the summer harvest was at mid-summer when it was presumed, based on information in the literature (Golley 1965), that the standing crop of cool-season species would be maximal and the warm-season species just getting started. The late-season harvest was scheduled to occur after the cessation of fall growth and after most of the plant nutrients were presumably in storage organs belowground. The validity of the assumptions and the effect of harvest dates on yield required verification, which was accomplished by the sampling scheme employed in 1988.

Abandoned soybean field

Total standing crop in AS plots harvested once in 1988, averaged over all treatments, increased from 3335 kg•ha^{-1} on May 23 to a maximum of 10555 kg•ha^{-1} on September 12, and then decreased to 4937 kg•ha^{-1} on December 9 (the final sample collection date). In AS plots harvested once during 1988, total standing crop was significantly effected by harvest date and nitrogen treatment (Table 27). The growth pattern was

Table 25. Mean regrowth response of old-field vegetation at an abandoned pasture to fertilizer and lime following a midsummer harvest in 1987

Vegetation component	Fertilizer Rate ($kg \cdot ha^{-1}$ of N-P-K)			Lime Rate ($kg \cdot ha^{-1}$)		
	0	56-56-135	Statistical significance[a]	0	4600	Statistical sigificance
Total yield	708	1047	NS	518	848	NS
Monocot yield	450	698	*[b]	444	704	*[b]
Misc. monocots	301	572	**	335	537	*
Panicum	8	10	NS	9	9	NS
Andropogon	141	117	NS	100	158	NS
Dicot yield	258	349	NS	251	355	NS
Rhus copalina	8	55	NS	3	60	NS
Misc. composites	196	235	NS	197	234	NS
Lespedeza	49	52	NS	46	54	NS
Misc. legumes	0	0	-	0	0	-
Rubus sp	2	3	NS	2	3	NS
Misc. dicots	2	3	NS	2	3	NS

[a]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

[b]Significant fertilizer x lime interaction.

Table 26. Combined effect[a] of fertilizer and lime on regrowth of monocots at an abandoned pasture in 1987

Lime treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Fertilizer Treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$ of N-P-K) 0-0-0	56-56-135
0	439a	448a
4600	461a	948b
$LSD_{0.05}$ = 243		

[a]Means followed by the same letter are not significantly different based on least significant difference (P = 0.05).

Table 27. Mean square and significance levels[a] for the effects of harvest date, nitrogen, and phosphorous on standing crop of old-field vegetation at an abandoned soybean field in 1988

Source of variation	Degrees of freedom	Standing Crop								
		Total	Monocot	Dicot	Solidago	Lespedeza	Trifolium	Rubus	Aster	Misc. dicots
		Plots Harvested Once Annually								
		$(X10^{-6})$	$(X10^{-5})$	$(X10^{-6})$	$(X10^{-6})$	$(X10^{-6})$	$(X10^{-5})$	$(X10^{-3})$	$(X10^{-6})$	$(X10^{-4})$
Block	2	2.97	14.54*	9.01	2.92	9.56*	1.50	5.69*	0.70	0.49
Harvest date (H)	9	100.27**	3.84	109.79**	26.68**	31.11**	1.25*	1.23	3.31*	2.63
Nitrogen treatment (Ntrt)	1	29.35**	59.56**	8.38	58.09**	24.38**	5.67**	1.92	1.48	5.33
Phosphorous treatment (Ptrt)	1	8.94	24.03*	20.94*	14.03*	1.13	1.21	4.42	0.01	0.71
H x Ntrt	9	2.16	2.27	2.70	2.70	6.95**	0.99	2.37	1.03	11.88
H x Ptrt	9	3.09	1.99	3.37	5.07	7.01	0.48	1.25	0.99	1.48
Ntrt x Ptrt	1	3.33	4.75	1.03	3.73	0.04	1.49	7.43*	0.61	0.39
H x Ntrt x Ptrt	9	4.05	3.49	4.83	1.22	4.87	0.50	1.03	0.69	1.22
Error	78	3.20	4.02	3.46	2.79	2.73	0.52	1.79	1.26	1.40
		Plots Harvested Twice Annually								
		$(X10^{-6})$	$(X10^{-5})$	$(X10^{-5})$	$(X10^{-6})$	$(X10^{-6})$	$(X10^{-5})$	$(X10^{-3})$	$(X10^{-5})$	$(X10^{-4})$
Block	2	3.65	25.90*	41.40*	0.90	0.88	3.60	1.99	1.13	3.23
Harvest date (H)	7	2.04	6.74	17.30	0.85	0.96*	7.55**	2.75	4.62**	12.31*
Nitrogen treatment (Ntrt)	1	2.72	8.25	6.71	17.69**	6.61**	1.71	8.30	0.94	0.21
Phosphorous treatment (Ptrt)	1	0.58	28.37*	9.61	0.71	0.41	5.25	1.48	0.55	5.70
H x Ntrt	7	2.40	10.63	15.06	0.85	0.55	1.13	1.40	0.94	4.03
H x Ptrt	7	1.03	10.03	20.57	1.68	0.15	1.49	2.56	0.88	3.10
Ntrt x Ptrt	1	1.45	4.89	36.72	2.62	0.57	1.04	0.74	1.13	11.45
H x Ntrt x Ptrt	1	1.13	6.80	13.32	0.91	0.25	0.75	2.59	0.24	7.58
Error	61	1.34	6.34	10.59	0.81	0.39	2.12	3.31	0.94	4.96

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

one of closely clustered standing crop values and absence of significant differences between treatments through July 6, at which time the early summer drought was broken by significant amounts of rainfall (Fig. 2). There was no clear and consistent separation between treatments until after the October sample was collected, at which time the treatment receiving no phosphorous or nitrogen (control) consistently exhibited the lowest standing crop values. There was a tendency for plots receiving both nitrogen and phosphorous to exhibit a slower rate of decline in standing crop during the fall than other treatment combinations.

The monocot component of the AS vegetation in plots harvested once during 1988 did not exhibit significant changes in standing crop throughout the period of study (net growth approximated 0 kg), averaging 737 $kg \cdot ha^{-1}$ over all sampling dates and treatments (Fig. 3). Nitrogen application significantly enhanced monocot standing crop from 514 $kg \cdot ha^{-1}$ in plots receiving no nitrogen fertilizer to 960 $kg \cdot ha^{-1}$ in plots receiving nitrogen. Phosphorous fertilization significantly reduced monocot standing crop from 816 $kg \cdot ha^{-1}$ in plots without phosphorous fertilizer to 596 $kg \cdot ha^{-1}$ in plots receiving phosphorous.

The dicot component, which accounted for an average of 89% of the total AS standing crop over all treatments and sample dates in plots harvested once, was responsible for most of the biomass changes that occurred during the course of the 1988 sampling year (Fig. 3). The dicot proportion was lowest on May 23 (75%) and highest during the fall (94 to 95% from September 7 through November 2). Phosphorous applications caused average standing crop to increase from 5542 $kg \cdot ha^{-1}$ to 6377 $kg \cdot ha^{-1}$, averaged over block, harvest date, and nitrogen treatment.

Solidago, *Aster*, and *Lespedeza* accounted for 64%, 25%, and 8%, respectively, of the dicot component of standing crop in plots harvested once annually, averaged over all sampling dates and treatments. The *Solidago* and monocot components were the major contributors to the increase in total standing crop attributed to the nitrogen treatment (Table 28). The leguminous components (*Lespedeza* and *Trifolium*) were negatively effected by nitrogen fertilization, thus reducing the overall

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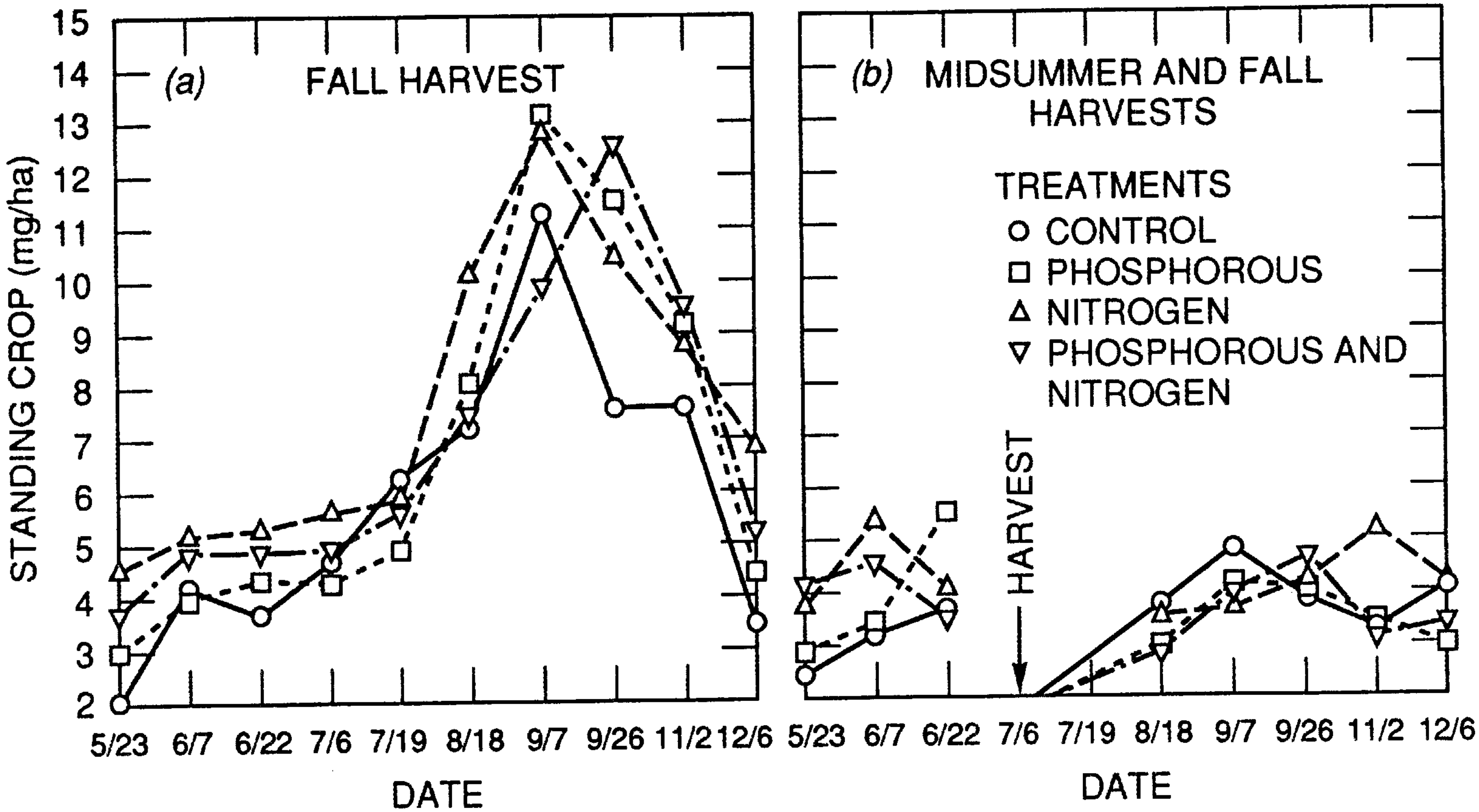

Fig. 2. Effect of harvest frequency, nitrogen fertilizer, and phosphorous fertilizer on standing crop of old-field vegetation at an abandoned soybean field in 1988.

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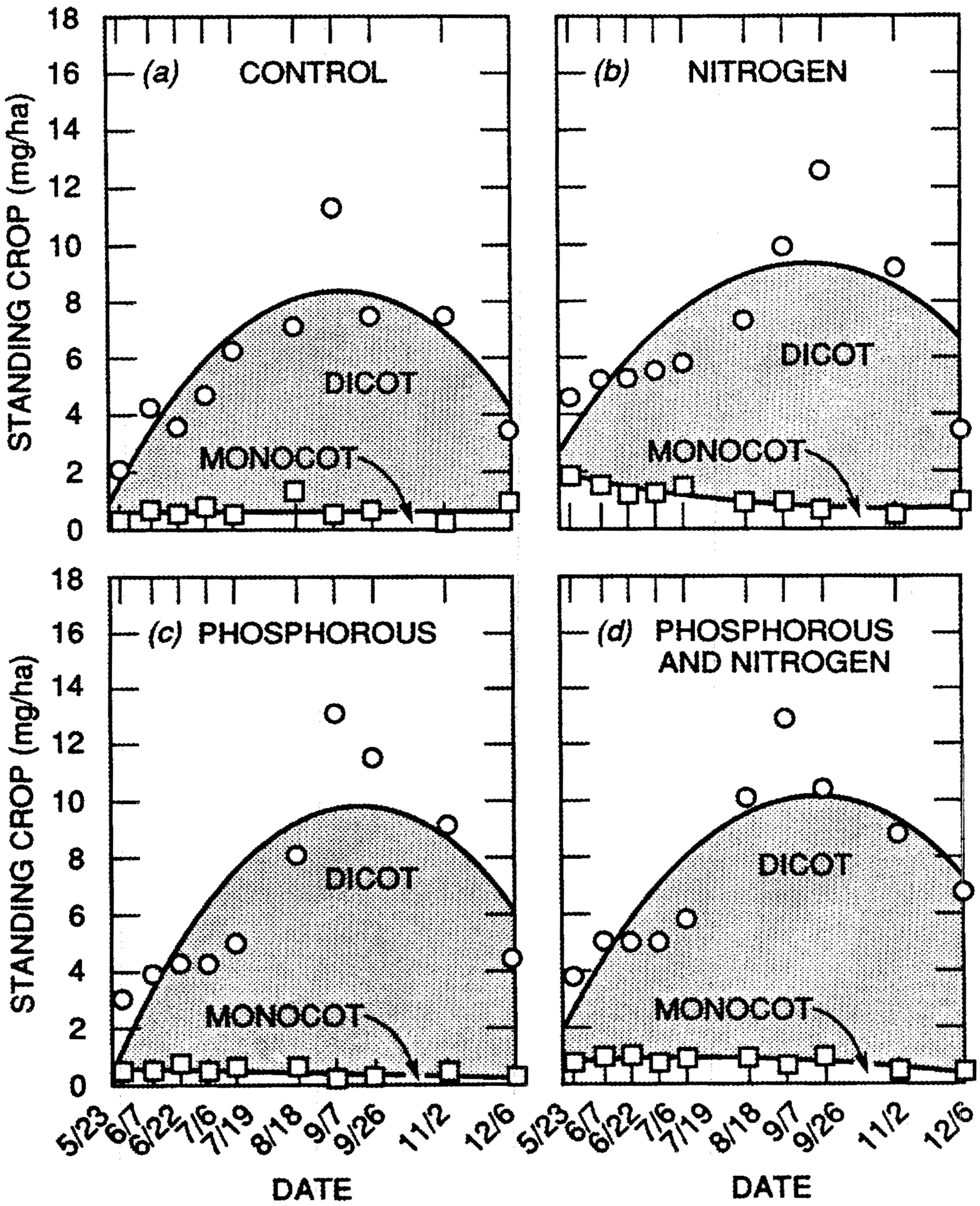

Fig. 3. Quadratic response functions for the effects of nitrogen and phosphorous fertilizer on growth of old-field vegetation at an abandoned soybean field.

Table 28. Effect of nitrogen and phosphorous fertilization on standing crop ($kg \cdot ha^{-1}$) of the dominant vegetative components of an old-field plant community on an abandoned soybean field in 1988

Vegetative component	Nitrogen treatment ($kg \cdot ha^{-1}$)			Phosphorous treatment ($kg \cdot ha^{-1}$)		
	0	87	Significance[a]	0	111	Sigificance[a]
Vegetation Harvested Once Annually						
Total	6228	7217	**	6449	6995	NS
Monocot	515	960	**	879	596	*
Dicot	5696	6225	NS	5543	6378	*
Solidago	3119	4510	**	3472	4156	*
Lespedeza	1969	1068	**[b]	1421	1616	NS[c]
Trifollium	146	8	**	109	45	NS
Rubus	10	18	NS[d]	21	8	NS
Aster	355	577	NS	456	476	NS
Miscellaneous	73	31	NS	59	44	NS
Vegetation Harvested Twice Annually						
Total	3684	3913	NS	3852	3742	NS
Monocot	1000	1182	NS	1239	937	*
Dicot	2658	2721	NS	2589	2791	NS
Solidago	1343	2204	**	1862	1674	NS
Lespedeza	673	147	**	342	484	NS
Trifollium	223	131	NS	106	251	NS
Rubus	27	8	NS	21	14	NS
Aster	160	98	NS	105	155	NS
Miscellaneous	123	115	NS	93	145	NS

[a]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.
[b]Significant harvest date x nitrogen treatment interaction.
[c]Significant harvest date x phosphorous treatment interaction.
[d]Significant nitrogen treatment x phosphorous treatment interaction.

positive effect of nitrogen application on total standing crop. The *Solidago* component was responsible for most of the positive phosphorous effect on dicot standing crop (Table 28). The negative effect of phosphorous fertilization on monocot standing crop offset the positive effect of phosphorous on *Solidago*, resulting in the lack of a significant phosphorous effect on total standing crop. In addition to the main effects, there were significant interactive effects for *Lespedeza* (sample date X nitrogen treatment and sample date x phosphorous treatment) and *Rubus* (nitrogen treatment X phosphorous treatment). The sample date interactions for *Lespedeza* were caused primarily by standing crop in plots receiving no nitrogen fertilizer recorded for August 18. The small size of the collected samples and the clumpiness of the *Lespedeza* growth habit probably contributed to increase the likelihood of a Type I experimental error (Snedicor and Cochran 1974). The nitrogen treatment X phosphorous treatment interaction for *Rubus* was due to the combination of a positive effect of nitrogen fertilizer in the absence of phosphorous fertilization with a negative effect of nitrogen fertilizer in the presence of phosphorous fertilizer (Table 29). Again, the relative rarity of *Rubus* increased the likelihood of Type I error.

Average total standing crop in AS plots harvested twice during 1988 remained relatively constant throughout the sampling period, increasing from 3240 kg•ha^{-1} on May 23 to 4228 kg•ha^{-1} on June 22, just prior to the midsummer harvest, and then increasing from essentially 0.0 kg•ha^{-1} immediately following the midsummer harvest to a maximum of 4170 kg•ha^{-1} on September 26, and then declining to 3557 kg•ha^{-1} on the final sampling date on December 12 (Fig. 2). In addition to the statistically significant sample date effect, there was significant interaction of sample date with nitrogen treatment on total standing crop (Table 27). Plots that were fertilized with nitrogen exhibited a decline in standing crop between June 7 and June 28 (Fig. 2); plots that were not fertilized with nitrogen continued positive growth during that period. This was a result of the severe drought that occurred during spring and early summer of 1988. After the midsummer harvest, there were only small

Table 29. Combined effect of nitrogen treatment and phosphorous treatment on standing crop ($kg \cdot ha^{-1}$) of *Rubus* from an abandoned soybean field in 1988[a]

Nitrogen treatment ($kg \cdot ha^{-1}$)	Phosphorous treatment	
	0	111
0	7a	12ab
87	32b	5a
LSD0.05 = 22		

[a]Means followed by the same letter were not significantly different based on least significant difference (P = 0.05).

(insignificant) differences in standing crop between the nitrogen treatments.

As was the case at the AS site harvested once in 1988, the monocot component of plots harvested twice at the AS site did not exhibit significant changes in biomass throughout the period of study (Table 27), averaging 1089 $kg \cdot ha^{-1}$ over all sample dates and treatments. Unlike the results with the plots harvested once, there were no significant treatment effects or interactions for the monocot component of plots harvested twice.

The dicot component accounted for an average of 71% of the total standing crop over all treatments that included two annual harvests, ranging from 62% on June 7 to 78% on June 28. The proportion of standing crop attributable to the dicots was lower, on average, in plots harvested twice than in those harvested once, and the proportion remained approximately constant over the course of the 1988 study period on twice harvested plots, in contrast to those harvested once. There were no significant harvest date, nitrogen fertilizer, or phosphorous fertilizer effects on dicot standing crop from plots harvested twice annually.

Among the dicot components, only *Solidago* and *Lespedeza* exhibited significant responses to nitrogen fertilization (Table 27). *Solidago* standing crop averaged 861 $kg \cdot ha^{-1}$ greater in plots that received nitrogen fertilizer than those receiving no nitrogen fertilizer, averaged across sample dates and phosphorous treatments. In contrast, *Lespedeza* standing crop was 526 $kg \cdot ha^{-1}$ (673 $kg \cdot ha^{-1}$ vs 147 $kg \cdot ha^{-1}$, respectively) less in plots that received nitrogen fertilizer than in plots that received no nitrogen fertilizer. The offsetting responses of *Solidago* and *Lespedeza* resulted in the lack of significant effects on dicot and total standing crop. Phosphorous fertilizer caused no significant effects on total standing crop for any of the vegetative components.

Abandoned pasture

Total standing crop in AP plots harvested once annually, averaged over all treatments, increased from 1148 $kg \cdot ha^{-1}$ on May 32 to 5946

$kg \cdot ha^{-1}$ on October 4, and then declined to 3565 $kg \cdot ha^{-1}$ on December 9 (Fig. 4). Total standing crop in plots harvested once was significantly affected by sample date and fertilizer treatment, and the sample date X fertilizer treatment and fertilizer treatment X lime treatment interactions (Table 30). Lime treatment alone did not significantly affect total standing crop. There were no clear and consistent separations between treatments between May 31 and July 28, the period of maximum growth rate. After July 28, the control treatment exhibited significantly less standing crop than the treatments receiving fertilizer, and plots receiving nitrogen exhibited greater standing crops than those not receiving nitrogen.

The monocot component of the AP vegetation in plots harvested once annually, which accounted for 62% of the total standing crop when averaged across all sample dates and treatments, exhibited statistically significant sample date and fertilizer treatment effects (Table 30). The effect of phosphorous and all interactions for monocot standing crop were not significant. Monocot standing crop in AP plots harvested once in 1988 increased from 822 $kg \cdot ha^{-1}$ on May 31 to a maximum of 4134 $kg \cdot ha^{-1}$ on November 9, and decreased to 3565 $kg \cdot ha^{-1}$ by December 9 (Fig. 5). The lack of significant interactions indicate that the slopes of the monocot standing crop curves in Fig. 5 are not significantly different. Fertilizer application increased monocot standing crop 58% (Table 31), from 2051 $kg \cdot ha^{-1}$ in plots receiving no fertilizer to 3241 $kg \cdot ha^{-1}$ in plots to which fertilizer was applied. The lack of a sample date X fertilizer treatment interaction indicated that the effect of fertilizer remained approximately constant throughout the sampling period. Among the monocots, *Festuca* was the dominant species, accounting for 46% of the monocot component, averaged over all sample dates and fertilizer treatments. The *Festuca* response to fertilizer and lime treatments were very similar to those for the total monocot component (Table 31). *Andropogon* and *Panicum* did not exhibit significant responses to fertilizer applications (Table 31). *Andropogon* standing crop was significantly reduced by lime application by a factor of 7, averaged over all sample dates and fertilizer treatments (Table 31).

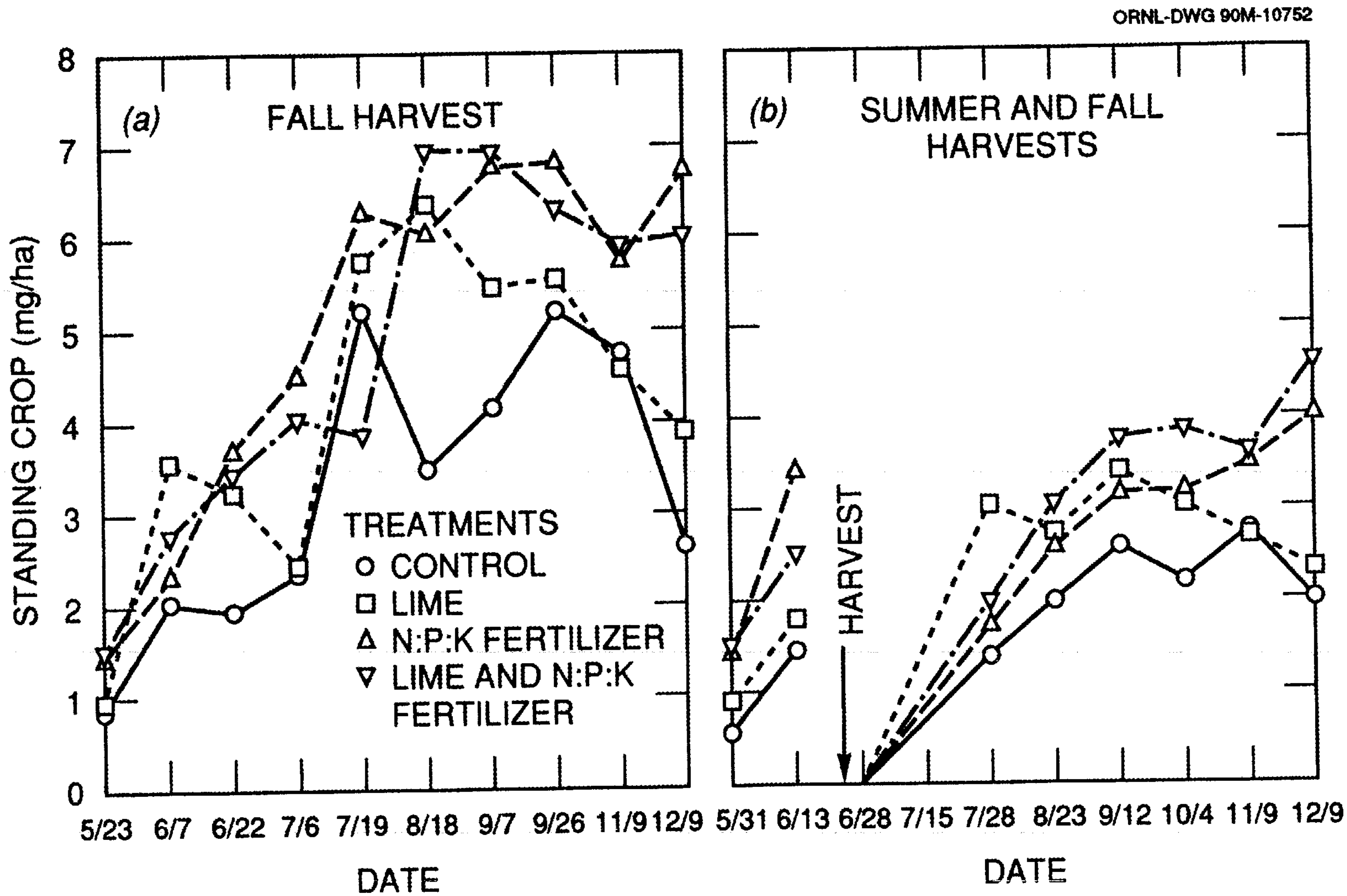

Fig. 4. Effect of harvest frequency, NPK fertilizer, and lime on standing crop of old-field vegetation at an abandoned pasture.

Table 30. Mean square and significance[a] levels for the effects of harvest date, fertilizer, and lime on standing crop of old-field vegetation at an abandoned pasture during 1988

Source of variation	Degrees of freedom	Monocot	Dicot	Total	Festuca	Andropogon	Panicum	Lespedeza	Legumes	Rhus	Rubus	Aster
		Plots Harvested Once Annually										
		($X10^{-6}$)	($X10^{-6}$)	($X10^{-6}$)	($X10^{-6}$)	($X10^{-5}$)	($X10^{-4}$)	($X10^{-6}$)	($X10^{-4}$)	($X10^{-6}$)	($X10^{-4}$)	($X10^{-5}$)
Block	2	1.83	8.02**	2.86	1.02	2.72	0.27	1.81*	1.28	10.83**	4.30*	1.37
Harvest date (H)	9	16.44**	8.85**	31.84**	8.49**	2.92*	5.50	1.12*	7.39*	2.51**	2.18	1.03
Fertilizer treatment (F)	1	42.45**	<0.01	41.88**	24.85**	0.29	7.43	0.23	0.35	0.13	6.35*	0.14
Lime treatment (L)	1	1.89	9.98**	3.19	0.52	8.41**	7.25	7.31**	0.82	0.47	9.54**	0.11
H*F	9	1.24	1.82	3.37*	0.57	0.68	1.58	0.33	0.64	1.27	1.26	0.38
H*L	9	0.81	2.38*	1.80	0.95	2.08	2.36	0.66	1.63	1.87*	1.71	1.05
F*L	1	0.18	7.90**	10.46*	0.67	0.38	5.02	2.49*	6.38	1.60	0.09	0.51
H*F*L	9	0.56	0.83	0.72	0.15	0.23	4.34	0.87	2.26	0.24	1.47	0.43
Error	78	1.03	1.13	1.60	0.55	1.19	2.85	0.45	3.46	0.87	1.19	0.70
		Plots Harvested Twice Annually										
		($X10^{-6}$)	($X10^{-5}$)	($X10^{-6}$)	($X10^{-6}$)	($X10^{-5}$)	($X10^{-4}$)	($X10^{-6}$)	($X10^{-4}$)	($X10^{-4}$)	($X10^{-4}$)	($X10^{-4}$)
Block	2	1.00	4.90	1.69	0.56	1.88	0.07	1.09**	5.72**	0.27	0.17	5.73*
Harvest date (H)	7	5.44**	4.33*	6.54**	3.01**	7.27**	1.12*	0.33	1.65	0.64	0.18	12.32**
Fertilizer treatment (F)	1	17.94**	0.49	16.11**	16.27**	1.89**	0.05	0.01	1.66	0.54	0.19	0.27
Lime treatment (L)	1	0.89	13.33*	4.41**	2.94**	4.98*	0.77	1.56**	0.86	0.08	0.11	11.79**
H*F	7	0.88	3.14	1.59*	0.58	1.06	0.35	0.21	0.71	0.76	0.13	2.93
H*L	7	0.31	2.79	0.53	0.37	1.56	1.08*	0.19	0.29	0.89	0.02	7.83**
F*L	1	0.02	6.77	0.94	0.09	0.43	1.64	1.17*	0.63	0.58	0.27	3.71
H*F*L	7	0.23	0.94	0.28	0.05	0.70	0.59	0.13	0.88	0.62	0.09	0.47
Error	62	0.44	1.92	0.58	3.32	0.99	0.48	0.17	0.89	0.78	0.10	1.51

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

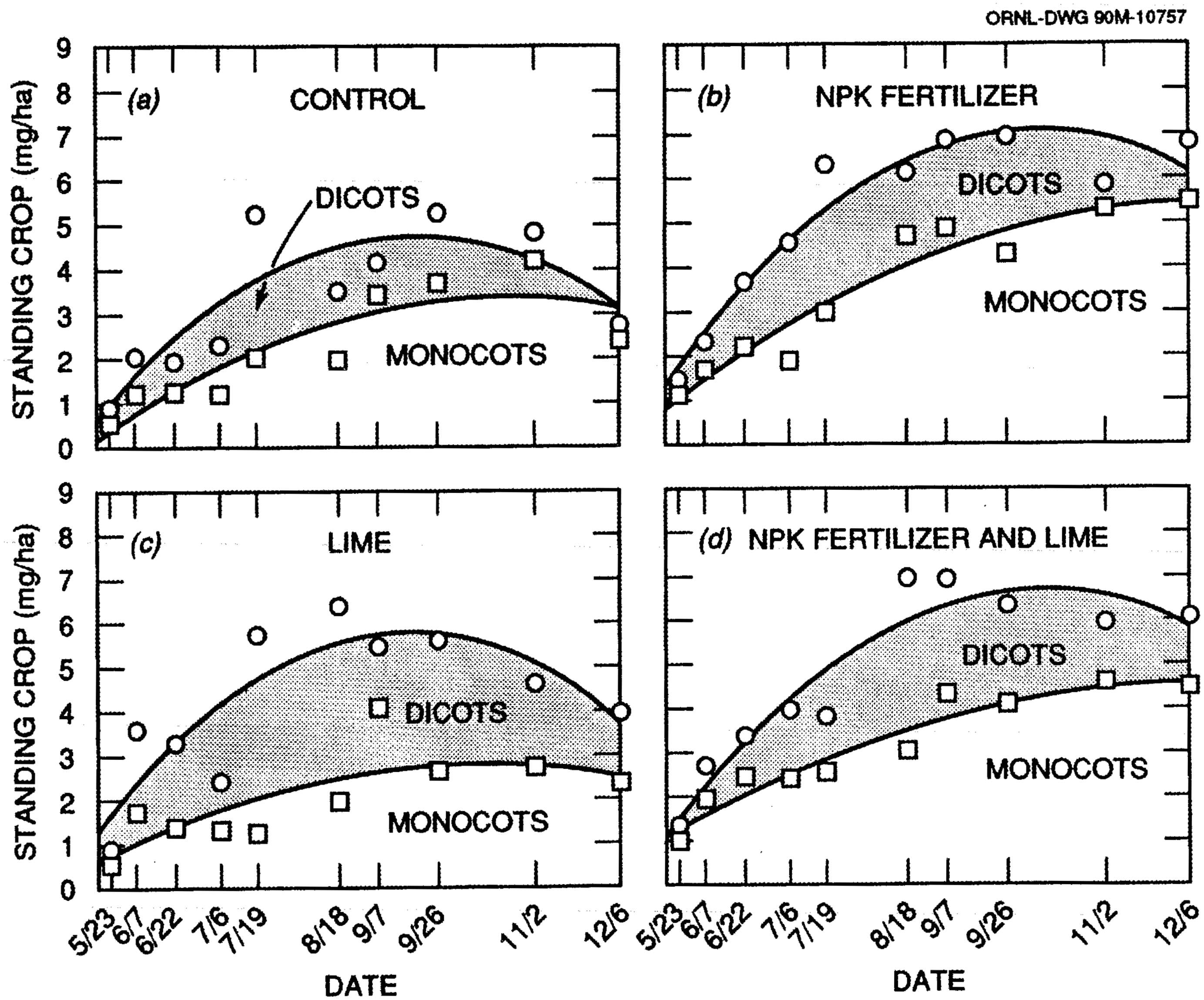

Fig. 5. Quadratic response functions for the effects of fertilizer and lime on growth of old-field vegetation at an abandoned pasture.

Table 31. Effect of fertilizer and lime on standing crop of an old-field plant community at an abandoned pasture in 1988

Vegetative component	Fertilizer treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$ of N-P-K) 0-0-0	56-56-135	Significance[a]	Lime treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$) 0	4600	Significance[a]
			Plots Harvested Once Annually			
Total	3695	4876	**	4122	4448	NS
Monocot	2051	3241	**	2771	2521	NS
Festuca	762	1672	**	1151	1283	NS
Andropogon	128	97	NS	196	28	**
Panicum	156	107	NS	156	107	NS
Dicot	1643	1635	NS	1351	1928	**
Lespedeza	627	539	NS	337	830	**
Other legumes	82	72	NS	69	85	NS
Rhus	652	718	NS	623	748	NS
Rubus	58	104	*	109	52	**
Aster	199	177	NS	198	179	NS
Misc. dicots	25	25	NS	16	34	NS
			Plots Harvested Twice Annually			
Total	2171	2990	**	2367	2795	**
Monocot	1687	2551	**	2023	2215	NS
Festuca	582	1406	**	819	1169	**
Andropogon	358	145	**	324	180	*
Panicum	35	30	NS	41	24	NS
Dicot	484	439	NS	344	580	*
Lespedeza	288	304	NS	169	423	**
Other legumes	60	34	NS	38	57	NS
Rhus	41	26	NS	30	36	NS
Rubus	22	13	NS	21	14	NS
Aster	31	35	NS	44	22	**
Misc. dicots	42	28	NS	42	27	NS

[a]* = significant with >95% confidence; ** = significant with 99% confidence; NS = not significant.

The dicot component of the AP vegetation in plots harvested once annually, which was dominated by *Lespedeza* (36%), *Rhus* (42%), and *Aster* (9%), exhibited statistically significant sample date and lime treatment effects, and significant sample date X lime treatment and fertilizer X lime treatment interactions (Table 30). Dicot standing crop, averaged over all fertilizer and lime treatments, increased from 325 $kg \cdot ha^{-1}$ on May 31 to a maximum value of 3064 $kg \cdot ha^{-1}$ on July 28, followed by a gradual decline to 1070 $kg \cdot ha^{-1}$ on November 9. Lime application caused an increase of dicot standing crop from 1351 $kg \cdot ha^{-1}$ to 1927 $kg \cdot ha^{-1}$, averaged over all sample dates and fertilizer treatments. The pattern of increased dicot standing crop in plots that received lime was consistent throughout the sampling period, except on July 15 and July 28 when the pattern was reversed (Fig. 4). This reversal was responsible for the significance of the sample date x lime treatment interaction. *Rhus*, which also exhibited a significant sample date X lime treatment interaction, was responsible for much of the variability that caused the sample date X lime treatment interaction for the dicot component. The fertilizer treatment X lime treatment interaction for dicots was primarily due to the positive response of *Lespedeza* to lime (4.3X) in the absence of fertilizer as opposed to the lack of a response to lime in the presence of fertilizer (Table 32).

Total standing crop in AP plots harvested twice annually, averaged over all treatments, increased from 1125 $kg \cdot ha^{-1}$ on May 31 to 2317 $kg \cdot ha^{-1}$ on June 13, immediately prior to the mid-summer harvest (Fig. 4). Following the midsummer harvest, total standing crop increased from essentially 0 $kg \cdot ha^{-1}$ to 3221 $kg \cdot ha^{-1}$ on September 12, and remained relatively constant through the final sample date on December 9. Sample date, fertilizer treatment, and lime treatment, and the sample date X fertilizer treatment interaction significantly affected total standing crop (Table 30). The remaining interactions for total standing crop were not statistically significant. Fertilizer application, averaged across all sample dates and lime treatments, enhanced total standing crop by 38%, from 2171 $kg \cdot ha^{-1}$ without fertilizer to 2990 $kg \cdot ha^{-1}$ with fertilizer (Table 31). The sample date X fertilizer treatment interaction was due to divergence of standing crop means between the two

Table 32. Combined effect of fertilizer and lime on standing crop of the dicot component of an old-field plant community on an abandoned pasture harvested once annually[a]

Lime treatment ($kg \cdot ha^{-1}$)	Fertilizer treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$ of N-P-K) 0-0-0	56-56-135
	Dicot Standing Crop	
0	1098a	1604ab
4600	2188c	1667bc
LSD0.05 = 548		
	Lespedeza Standing Crop	
0	237a	437ab
4600	1018c	642b
LSD0.05 = 346		

[a]Means followed by the same letter are not significantly different based on least significant difference (P = 0.05).

fertilizer treatments through the late summer and fall. This response to fertilizer closely resembles that observed in plots harvested once annually.

The monocot component of the AP vegetation in plots harvested twice annually, which accounted for 82% of the total standing crop averaged across all sample dates and treatments, was significantly affected by sample date and fertilizer treatment (Table 30). The lime treatment effect and the sample date, fertilizer treatment, and lime treatment interactions were not significant. Monocot standing crop generally increased throughout the sampling period in all treatments (Fig. 5). Fertilizer application enhanced monocot standing crop an average of 51%, primarily by increasing the *Festuca* component from 582 $kg{\bullet}ha^{-1}$ without fertilizer addition to 1406 $kg{\bullet}ha^{-1}$ with fertilizer addition (Table 31). *Andropogon* exhibited a significant negative response to fertilizer application, with average standing crop reduced from 358 $kg{\bullet}ha^{-1}$ to 145 $kg{\bullet}ha^{-1}$ by the addition of fertilizer.

The dicot component of the AP vegetation in plots harvested twice annually showed significant sample date and lime treatment effects (Table 30). Dicot standing crop increased from 182 $kg{\bullet}ha^{-1}$ on May 31 to 483 $kg{\bullet}ha^{-1}$ on June 13, just prior to the midsummer harvest, and increased from essentially 0 $kg{\bullet}ha^{-1}$ immediately following the midsummer harvest to a maximum standing crop of 743 $kg{\bullet}ha^{-1}$ on September 12 and thereafter decreased to 194 $kg{\bullet}ha^{-1}$ on December 9, the final sampling date (Fig. 6). Most of the growth differences described by the changes in dicot standing crop were accounted for by the *Lespedeza* component, which made up 64% of the dicot component. Lime application enhanced dicot standing crop from 344 $kg{\bullet}ha^{-1}$ without lime to 580 $kg{\bullet}ha^{-1}$ with lime (Table 31), primarily by its effect on *Lespedeza*, which paralleled the changes in dicot standing crop.

Yield Summation Over 3 Years

The 3-year yield summations of the successional vegetation from the AS and AP sites are shown in Table 33. The AS site was 27% more productive than the AP site, averaged over all treatments. The yield differences between harvest frequencies were small (3% at the AS, 1% at

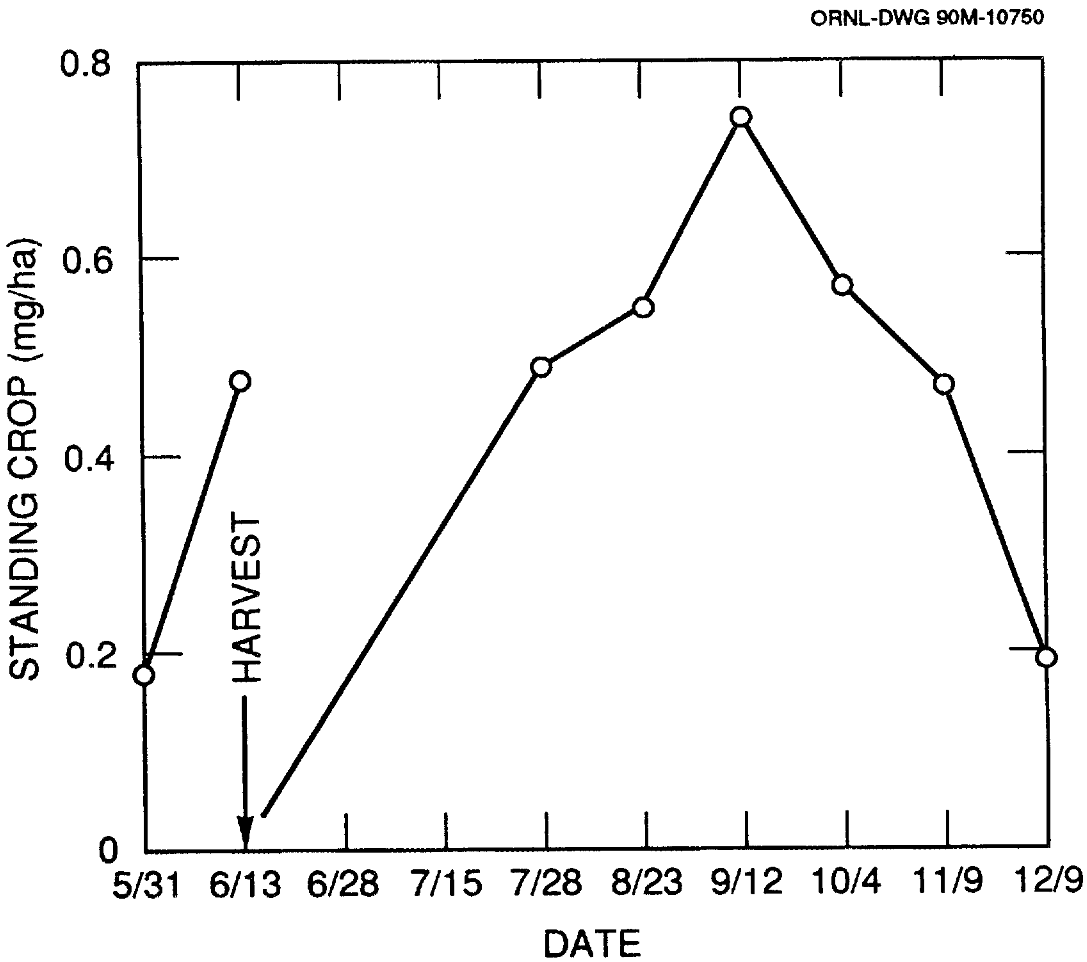

Fig. 6. Changes in the standing crop of the dicot component of a successional plant community in an abandoned pasture harvested twice annually

Table 33. Mean yield response of vegetation from two old-field plant communities to fertilizer, lime, and harvest frequency over 3 years

Abandoned Soybean Field

Harvest frequency	Fertilizer ($kg \cdot ha^{-1} \cdot yr^{-1}$) Nitrogen	Phosphorous	Yield ($kg \cdot ha^{-1}$) 1986	1987	1988	Total
1	0	0	3205	5101	5750	14056
1	0	111	3959	5091	6995	16045
1	87	0	3909	4153	7740	15802
1	87	111	4082	6559	8450	19091
2	0	0	3430	4511	7794	15735
2	0	111	3786	5543	8738	18067
2	87	0	3385	5157	8437	16979
2	87	111	3938	5702	6830	16470

Abandoned Pasture

Harvest frequency	N-P-K fertilizer ($kg \cdot ha^{-1}$)	Lime ($kg \cdot ha^{-1} \cdot yr^{-1}$)	Yield ($kg \cdot ha^{-1}$) 1986	1987	1988	Total
1	0-0-0	0	3093	1615	3290	7998
1	0-0-0	4600	3607	2643	4110	10360
1	56-56-135	0	3499	3684	6095	13278
1	56-56-135	4600	3882	4442	6010	14334
2	0-0-0	0	3696	1701	3937	9334
2	0-0-0	4600	4648	2618	4300	11566
2	56-56-135	0	4915	3049	7243	15207
2	56-56-135	4600	4958	4132	6589	15679

the AP). The vegetation at the AP site responded positively to both lime (15%) and NPK fertilizer (51%) averaged over harvest frequency. The vegetation at the AS site responded positively to both nitrogen (7%) and phosphorous (11%) fertilizer.

DISCUSSION

The levels of productivity measured in this experiment were within the range reported for diverse natural vegetation types in the United States. For example, a number of investigators reported annual standing crop and net primary productivity measurements between 1513 $kg \cdot ha^{-1}$ to 4940 $kg \cdot ha^{-1}$ in 1- to 3-year old-fields without application of soil amendments over several years at the Savannah River Plant near Barnwell, South Carolina (Odum 1960; Golley 1965; Golley and Gentry 1965; Bakelaar and Odum 1978). Yield measurements ranging between 3000 $kg \cdot ha^{-1}$ and 10000 $kg \cdot ha^{-1}$, as in this report, are somewhat lower than the maximum yields reported for switchgrass (*Panicum virgatum*) in screening trials for energy feedstock potential in the southeastern and midwestern United States during the same years (1986-1988) that the present experiment was under way (Turhollow 1988). These years were characterized by record setting drought in the southeastern and midwestern regions, so yields for perennial crops and successional vegetation are probably on the low end of expected long-term average yield distributions.

The productivity of old-field vegetation can be affected by a number of factors, including soil amendments such as fertilizers and lime. In the present study, and in previous efforts, it has been shown that mixed-species plant communities respond positively to fertilizer applications (Golley and Gentry 1965; Mellinger and McNaughton 1975; Bakelaar and Odum 1975; Baker 1976; Kirchner 1977; Reed 1977; Maly and Barrett 1984; Tilman 1987). Both nitrogen and phosphorous have been shown to enhance productivity of old fields. Tilman (1987) measured standing crop of vegetation in old fields in Michigan ranging in age since disturbance from 14 to 48 years to which 0 to 272 $kg\text{-}N \cdot ha^{-1} \cdot yr^{-1}$ was applied. Standing crop ranged from approximately 1000 $kg \cdot ha^{-1}$ in treatments without nitrogen additions up to 9000 $kg \cdot ha^{-1}$ in fields receiving the maximum amount of N-fertilizer. The amount of response varied from year to year within sites and between old-fields of different age. Reed (1977) measured the response of an old field 6 years after abandonment to different nitrogen fertilizer application schedules at a rate of 450 $kg\text{-}N \cdot ha^{-1} \cdot yr^{-1}$. Peak standing crop averaged 12144 $kg \cdot ha^{-1}$ in treatments receiving nitrogen, a 48% increase over the control treatment. Baker (1976) reported increased yields of 13 previously ill-managed pastures in West Virginia in response to lime, potassium, and phosphorous applications. The average yield enhancement due to lime and potassium plus phosphorous application was 16%. No nitrogen fertilizer was included in that effort. The dicot components, primarily species of the genus *Trifolium*, were enhanced during the first 1-3 years by fertilizer applications but were suppressed by the more competitive monocots in later years.

Other factors that have been shown to affect the productivity and yield of mixed-species plant communities include rainfall (Odum 1960), irrigation (Kirchner 1977), soil factors such as drainage and clay and silt percentage (Odum 1960), and the selective removal of members of the plant community (Pinder 1975). Although old field productivity varies with the time since the field was abandoned, there seems to be no regular pattern to the fluctuations, indicating that site productivity, as affected by climatic variables such as rainfall, remains approximately constant, rather than changing as different species become dominant during the successional sequence (Mellinger and McNaughton 1975; Odum 1960). Fertilizer applications tend to increase site productivity independent of the successional stage.

The complexities of competition between species in multi-species plant communities were demonstrated by the responses of the vegetation to the perturbations imposed on the plant community in this experiment. The legume components *Lespedeza*, *Trifolium*, and *Desmodium* were generally suppressed by fertilizer treatments that stimulated productivity of the community dominants. At the AS site, the legumes were less dominant when *Solidago* production was enhanced by fertilizer application. Likewise at the AP site, the legumes were less dominant in fertilizer treatments that enhanced monocot production. It is presumed that the nitrogen fixing capability of the legumes favored their competitiveness in situations of nitrogen limitation, an advantage that lessened as nitrogen became less limiting. Competition for other limiting resources, such as water, could also be involved.

Harvest frequency was the variable of greatest influence on botanical composition in the present experiment. At the AS site, which was dominated by *Solidago*, midsummer harvest increased the proportion of biomass from monocots and the annual and biennial composites. Removal of the apical meristems of the tall-growing *Solidago* in the midsummer harvest gave competitors capable of quickly capturing the site the competitive advantage. Much of the advantage was captured by *Datura* in 1986, and by the monocots and the annual and biennial composites in 1987 and 1988. At the AP site, monocots, especially *Festuca*, *Andropogon*, and *Tridens* were favored in the two-cut system.

The changes in standing crop over the course of the growing cycle is an important variable for maximizing the yields that can be taken from successional vegetation. The results of the experiment conducted in 1988 that considered the effect of different harvest dates demonstrated that the yield measurements collected during 1986 and 1987 were underestimates of the maximum potential yield that was possible from these sites. The midsummer harvests in this (all 3 years) experiment were conducted during the period of maximum productivity. Delaying the midsummer harvest would have increased the biomass in that harvest. This experiment did not consider the effects of a delayed midsummer harvest on the yield that could be expected from a subsequent fall harvest. An earlier fall harvest would also have increased the measured yield in these experiments, especially in the single-cut treatments. In treatments that included one annual harvest, the date of maximum standing crop occurred during September at the AS site and late September through early October at the AP site. The late October harvest resulted in a loss from 10% to 15% of the biomass available for harvest at the AS site, and from 4% to 7% at the AP site, compared with the yield that would be expected from an earlier harvest. The timing of the fall harvest date had a smaller yield effect in the two-cut treatments.

Successional vegetation characteristic of abandoned agricultural lands are capable of producing significant quantities of biomass suitable for use as feedstock material for conversion to liquid and gaseous fuels. With no soil amendments yields summed over 3 years, characterized by the most prolonged drought on record, was approximately 8 $Mg \cdot ha^{-1}$ on an abandoned pasture and 14 $Mg \cdot ha^{-1}$ on an abandoned soybean field. Addition of modest amounts of fertilizer and lime doubled yields at the AP site, and fertilizer nitrogen and phosphorous increased yields approximately 35% at the AS site. There was no evidence of a yield reduction due to repeated harvests during the 3-year time course of this experiment.

BIOCHEMICAL COMPOSITION OF SUCCESSIONAL VEGETATION

INTRODUCTION

In consideration of using biomass as an energy feedstock, a number of issues concerning its suitability must be addressed. The previous chapter addressed issues related to the potential productivity of successional vegetation. The present chapter will address the chemical suitability of successional vegetation as an energy feedstock. There are currently two major pathways under consideration for conversion of terrestrial biomass to liquid or gaseous energy products, thermochemical and biochemical (USDOE 1988, Butner et al. 1988). The chemical composition of the successional vegetation harvested in 1987 was determined in order to identify factors unfavorable for specific conversion processes and to compare the chemical composition to that of other candidate feedstock materials.

In thermochemical conversion, the biomass is rapidly heated in the absence of oxygen, resulting in volatilization of the organic materials, which are then collected as combustible gases and liquids. This technique is harsh and not specific with respect to the chemical composition of the feedstock. In general, the entire organic component of the biomass feedstock is suitable for conversion. Low protein content is desirable due to environmental concerns related to nitrogen oxide air pollution and low ash content is desired in order to avoid deposition of inorganic scale on reactor vessel surfaces and disposal of solid waste.

Biochemical conversion processes, which involve breaking the cellulose and hemicellulose components of biomass down to their constituent sugars, are more sensitive to the chemical composition of the feedstock. A pretreatment with either weak or strong acid is used to disassociate the fibrous components of the cell walls so that the enzymes introduced into the reaction medium or produced by microorganisms in the medium will be able to access the chemical bonds that must be broken. Cellulose and hemicellulose are the desired chemical feedstock components. Ash and lignin are undesirable components because they are not converted in the biochemical processes. Proteins are also an undesirable biomass constituent because of their tendency to form undesirable by-products disposal requirements for nitrogen-containing residues.

MATERIALS AND METHODS

The dried plant material from the dominant species (those whose harvested sample was greater than 100 g) from each of the two 1987 harvests were analyzed with the Van Soest method to determine the following percentages: neutral detergent fiber, acid detergent fiber, lignin, nitrogen, and ash (Goering and Van Soest 1970). Cellulose, hemicellulose, cell contents, and protein were calculated from these results. Cell contents are the soluble components of the biomass calculated by subtracting the neutral detergent fiber, protein, and ash components from 100%. Due to the costs of the biochemical analyses, only three of the four blocks were used for chemical analysis. Data for the individual species were subjected to analysis of variance to determine the effects of the various treatments on chemical composition of the individual samples. Chemical yields were calculated based on the average proportion of the chemical components and the biomass yield on a plot-by-plot basis. When there were no statistically significant effects of treatments on chemical composition, the overall mean chemical proportions were used as multipliers for calculation of chemical yield. When there were statistically significant effects or interactions of treatments on chemical composition, the mean chemical proportions for the significant effects were used as multipliers for calculation of chemical yield for the individual plant components. Total plot chemical yields were calculated by summing the chemical yield contributions of the individual components.

RESULTS

Abandoned Soybean Field

Effect of harvest date

The effect of harvest date on the major chemical constituents of three sorting categories from the AS site are shown in Fig. 7. The

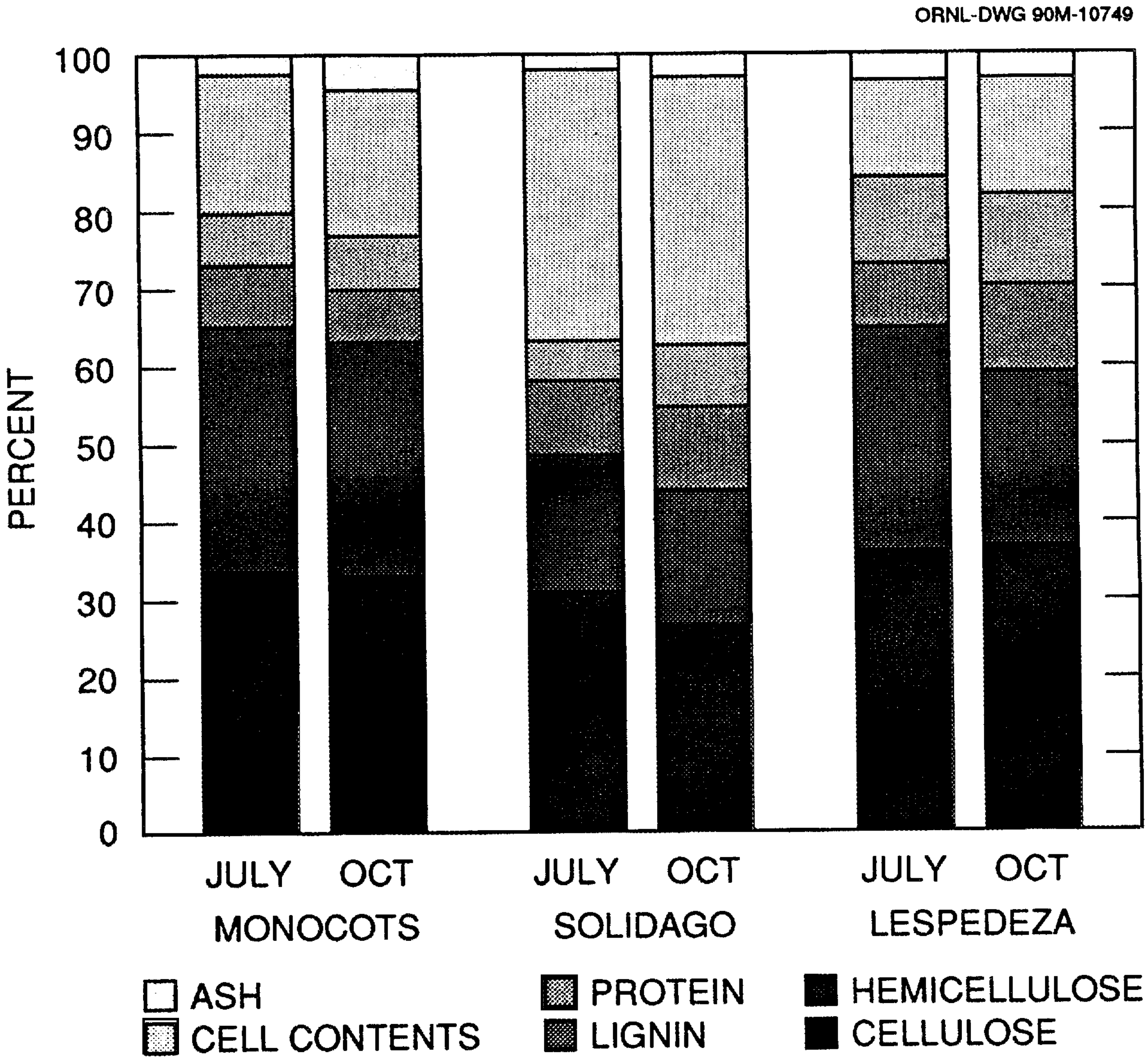

Fig. 7. Chemical composition of successional vegetation in an abandoned soybean field

chemical composition of the monocot group and *Solidago* was unaffected by harvest date. For *Lespedeza* the hemicellulose proportion was greater, primarily at the expense of cell contents, in the October harvest than in the July harvest.

Effect of treatments within harvest dates

In the midsummer harvest, significant treatment effects were restricted to the effects of phosphorous fertilizer on lignin content of *Solidago* (Table 34). The mean chemical compositions for monocots, *Lespedeza*, other legumes, miscellaneous dicots, and *Solidago* are shown in Table 35. Cellulose content ranged from 27.8% in the miscellaneous dicots to 41.6% in the miscellaneous legumes (primarily *Desmodium* sp). Total fiber content (the sum of cellulose, hemicellulose, and lignin) was lowest in the miscellaneous dicots (51.8%) and *Solidago* (between 56.8% and 60.3%, depending on nitrogen and phosphorus fertilizer treatments). The monocots and legumes were approximately equal in fiber content, averaging between 71% and 74%. Ash content was greatest in the legumes (3.4% to 4.8%). Lignin content of *Solidago* was less in treatments receiving phosphorous fertilizer (11.7%) than in treatments without phosphorous fertilizer (14.7%).

Harvest frequency was the experimental variable most responsible for significant effects on chemical constituents of vegetation in the fall harvest (Table 34). For *Solidago*, total fiber contents constituted a greater proportion of the aboveground biomass in treatments that included one annual harvest, at the expense of protein and cell contents (Table 35). Ash content of *Solidago* was not significantly affected by harvest frequency. Hemicellulose content of the monocots was greater in treatments that included a single annual fall harvest, at the expense of lignin and cell contents. Protein and cell contents were significantly greater in the two-harvest treatments than in the single harvest treatments. Nitrogen fertilization significantly affected the ash content of *Solidago* and the cell contents component of *Lespedeza*. There was insufficient regrowth of the miscellaneous composites category following the summer harvest for chemical analysis. Therefore, no statistical tests for harvest frequency were possible. There were no

Table 34. Statistical significance of treatment effects and interactions on the chemical composition of old field vegetation[a]

	Abandoned Soybean Field Chemical						
	Midsummer harvest			Fall harvest			
component composites[b]	Monocots	Solidago	Lespedeza	Monocots	Solidago	Lespedeza	Other
Cellulose	-	-	-	-	FREQ**	-	-
Hemicellulose	-	.	-	FREQ*	FREQ**	-	-
Lignin	-	P	-	FREQ*	FREQ*	-	-
Protein	-	-	-	-	FREQ**	FREQ**	-
Cell contents	-	-	-	-	FREQ**	FREQ*;N**	-
Ash	-	-	-	N*	-	-	-

	Abandoned Pasture						
Chemical	Midsummer harvest			Fall harvest			
component	Monocots	Lespedeza	Rhus	Monocots	Composites	Lespedeza	Rhus
Cellulose	F*	L*	-	FREQ**;F*	-	-	F*
Hemicellulose	F*	-	-	FREQ**;F**;L**	-	-	-
Lignin	-	-	-	-	-	-	-
Protein	F*	L*	-	FREQ**;F**	-	FREQ*;L**	-
Cell contents	-	-	-	F**;FREQXL*		-	-
-							
Ash	-	-	-	FREQ**;FREQXL*	-	-	-

[a]Abbreviations in the table are defined as follows: dash (-) - no statistically significant effects; FREQ - harvest frequency effect; P - phosphorous fertilizer effect; N - nitrogen fertilizer effect; F - fertilizer (N-P-K) effect; L - lime treatment effect; * - significance with 95% confidence; ** - significant with 99% confidence.

[b]Insufficient regrowth following the summer harvest for chemical analysis of the fall harvest. Therefore, statistical tests for harvest frequency effects and interactions were not possible.

Table 35. Chemical composition (%) of old-field vegetation at an abandoned soybean field in 1987

	Summer harvest	Fall Harvest: Harvest frequency 1	Fall Harvest: Harvest frequency 2	Significance[a]
Solidago				
Cellulose	32.5	26.6	17.3	**
Hemicellulose	31.7	18.2	14.6	**
Lignin	9.3	12.5	9.8	*
Protein	6.7	5.8	10.1	**
Cell contents	18.3	35.0	46.1	**
Ash	1.6	1.9	2.1	NS
Lespedeza				
Cellulose	34.7	36.8	33.0	NS
Hemicellulose	29.0	22.0	23.6	NS
Lignin	10.0	13.3	9.5	NS
Protein	10.8	10.6	14.3	**
Cell contents	12.0	15.1	17.1	*
Ash	3.4	2.2	2.5	NS
Monocots				
Cellulose	32.5	31.5	30.1	NS
Hemicellulose	31.7	26.1	33.1	*
Lignin	9.3	10.5	8.2	*
Protein	6.7	6.7	7.1	NS
Cell contents	18.3	22.5	19.0	NS
Ash	1.6	2.8	2.5	NS
Other legumes				
Cellulose	41.6	(absent in fall harvest)		
Hemicellulose	21.4			
Lignin	8.1			
Protein	12.2			
Cell contents	11.9			
Ash	4.8			
Miscellaneous dicots				
Cellulose	27.8	30.6	(no regrowth following summer harvest)	
Hemicellulose	12.1	17.9		
Lignin	11.9	11.2		
Protein	6.7	5.1		
Cell contents	39.8	33.7		
Ash	1.9	1.5		

[a]Harvest frequency effect: NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

statistically significant nitrogen fertilizer or phosphorous fertilizer treatment effects or interactions for the miscellaneous composites.

Effect of treatments on chemical yields

The mean chemical yields per hectare (the sum of the chemical yields for each of the vegetative components over the 1987 growing season) for all treatment combinations are shown in Table 36. Cellulose yields ranged from 1303 $kg \cdot ha^{-1}$ in plots receiving nitrogen and harvested once annually to 1997 $kg \cdot ha^{-1}$ in plots receiving fertilizer and lime and harvested once per year. Hemicellulose yields ranged from 805 $kg \cdot ha^{-1}$ in plots receiving nitrogen and harvested twice to 1218 $kg \cdot ha^{-1}$ in plots receiving nitrogen and phosphorous and harvested once per year. At the AS site, phosphorous significantly enhanced lignin, cell content, and ash yields (Table 37). Vegetation in the plots receiving phosphorous fertilizer exhibited a 20% increase in ash content (Table 38), an amount comparable to the enhancement of biomass productivity by phosphorous fertilization (Table 15). In addition, harvest frequency significantly affected the ash yield (Table 37). Ash yield was 24% greater in the double-cut system than in the single-cut system (Table 39). The effects of the other treatment-chemical component combinations were not statistically significant (Table 37).

Abandoned Pasture

Effect of harvest date

The overall mean proportions of the major biochemical classes of compounds for three species (or groups) from the AP site are shown in Fig. 8. As in the AS site, the chemical composition of the monocots remained essentially constant between the July and November harvests. *Rhus* and *Lespedeza* responded differently, with the fiber content greater in the November harvest than in the July harvest. The increase of the fiber content of *Rhus* and *Lespedeza* was primarily at the expense of cell contents. The fiber component ranged from 40% for *Rhus* in the July harvest to almost 90% for *Lespedeza* in the November harvest.

Table 36. Effect of fertilizer, lime, and harvest frequency on the chemical yield of components of old-field vegetation

Abandoned Soybean Field

Harvest frequency	Fertilizer (kg•ha⁻¹) Nitrogen	Phosphorous	Yield (kg•ha⁻¹) Cellulose	Hemicellulose	Lignin	Cell contents	Protein	Ash	Total
1	0	0	1692.1	1001.0	465.6	1367.4	369.3	172.9	5068.3
1	0	111	1550.0	949.9	476.3	1451.8	340.5	151.7	4920.2
1	87	0	1303.7	805.2	434.3	1175.0	284.8	129.3	4132.3
1	87	111	1997.0	1218.9	662.2	1871.4	421.9	205.0	6375.5
2	0	0	1403.7	1054.2	398.7	1003.3	375.7	173.2	4408.9
2	0	111	1592.7	1174.8	487.8	1547.9	417.5	208.6	5429.3
2	87	0	1560.9	1197.4	452.8	1300.9	425.7	193.0	5130.7
2	87	111	1676.5	1199.5	528.4	1685.6	430.2	239.5	5759.7

Abandoned Pasture

Harvest frequency	N-P-K fertilizer (kg•ha⁻¹)	Lime (kg•ha⁻¹)	Yield (kg•ha⁻¹) Cellulose	Hemicellulose	Lignin	Cell contents	Protein	Ash	Total
1	0-0-0	0	695.5	543.3	175.8	418.6	140.1	74.0	2048.3
1	0-0-0	4600	1365.1	935.9	373.8	743.6	193.6	131.3	3743.3
1	56-56-135	0	1823.3	1354.3	418.3	1154.4	530.1	184.9	5465.3
1	56-56-135	4600	2268.3	1609.9	507.8	1395.5	340.3	231.6	6353.4
2	0-0-0	0	516.9	477.1	131.8	426.9	115.1	48.0	1715.8
2	0-0-0	4600	699.7	723.0	211.9	541.1	197.8	52.8	2426.3
2	56-56-135	0	885.9	892.3	227.7	616.0	203.6	65.3	2890.8
2	56-56-135	4600	1294.4	1233.8	313.6	918.1	293.3	106.3	4159.5

Table 37. Analysis of variance for the effect of fertilizer, lime, and harvest frequency on the chemical yields of old-field vegetation from an abandoned pasture

Source of variation	df	F-ratio and significance levela					
		Cellulose	Hemicellulose	Lignin	Cell contents	Protein	Ash
			Abandoned Soybean Field				
Block	3	2.08	1.77	1.87	0.81	2.63	1.27
Frequency (FREQ)	1	0.30	2.77	0.97	0.49	2.44	6.14*
Nitrogen (N)	1	0.29	0.38	2.08	2.00	0.16	0.93
Phosphorous (P)	1	2.34	1.54	5.44*	13.33**	1.08	4.72*
FREQ*N	1	0.11	0.06	0.12	0.20	0.20	0.43
FREQ*P	1	0.19	0.38	0.18	0.10	0.17	0.19
N*P	1	1.85	0.78	1.39	0.93	0.75	2.96
FREQ*N*P	1	2.64	2.23	1.78	2.71	1.86	1.87
Error M.S. ($X10^4$)	215.66	7.64	1.49	10.97	1.11	1.97	
			Abandoned Pasture				
Block	3	0.04	>0.01	0.26	0.81	1.67	0.56
Frequency (FREQ)	1	37.15**	10.67**	26.78**	10.89**	5.40*	52.32**
Fertilizer (F)	1	43.83**	49.70**	25.31**	28.39**	18.02**	34.09**
Lime (L)	1	14.21**	13.05**	15.79**	7.18*	0.05	9.64**
FREQ*F	1	5.56*	2.67	2.46	5.02*	4.31*	8.46**
FREQ*L	1	1.33	0.03	1.13	0.17	3.30	1.45
F*L	1	>0.01	0.01	0.81	0.08	1.94	0.28
FREQ*F*L	1	0.09	0.46	1.00	0.55	2.17	0.93
Error M.S. ($X10^4$)	210.23	5.85	0.65	6.72	1.44	0.12	

[a]* - statistical significance with 95% confidence; ** - statistical significance with 99% confidence.

Table 38. Effect of phosphorous fertilizer on the chemical yield of old-field vegetation from an abandoned soybean field in 1987

Phosphorous treatment	Yield (kg•ha^{-1})					
	Cellulose	Hemicellulose	Lignin[a]	Cell contents[b]	Protein	Ash[a]
0	1490.1	1014.4	437.9	1211.7	363.9	167.1
1	1704.0	1135.8	538.7	1639.2	402.5	201.2

[a]Means significantly different (P = 0.05) based on analysis of variance.
[b]Means significantly different (P = 0.01) based on analysis of variance.

Table 39. Effect of harvest frequency on the chemical yield of old-field vegetation from an abandoned soybean field in 1987

Harvest frequency	Yield (kg•ha^{-1})					
	Cellulose	Hemicellulose	Lignin	Cell contents	Protein	Ash[a]
1	1635.7	993.7	509.6	1166.4	354.1	164.7
2	1558.5	1156.5	466.9	1384.4	412.3	203.6

[a]Means significantly different (P < 0.05) based on analysis of variance.

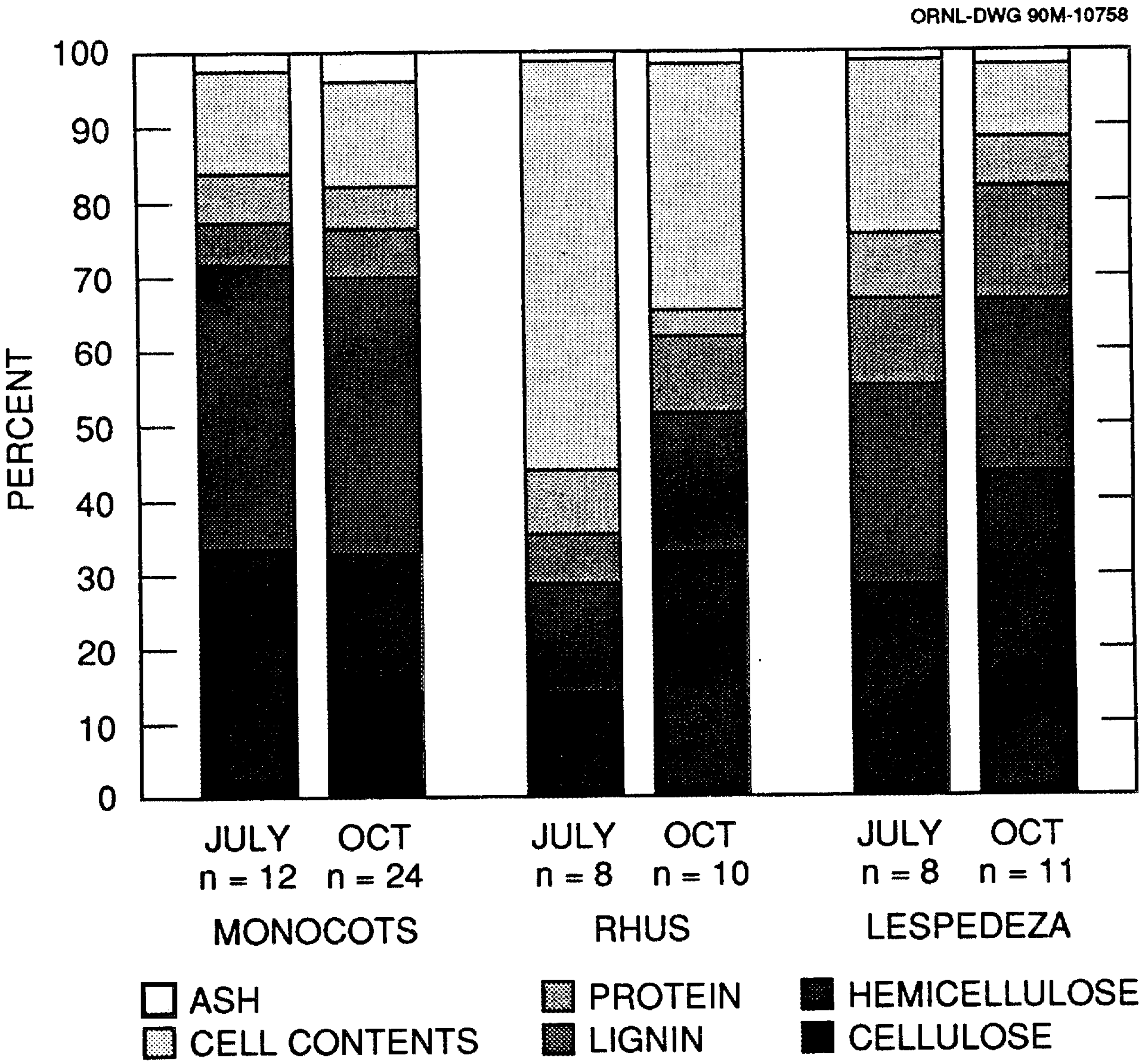

Fig. 8. Chemical composition of successional vegetation in an abandoned pasture.

Effect of treatments within harvest dates

Midsummer harvest. Fertilizer application significantly affected cellulose, hemicellulose, and protein content of the monocots harvested in July at the AP site (Table 34). Fertilizer application enhanced the cellulose fraction (3%) and reduced the hemicellulose (3%), protein (1%), and ash (0.5%) fractions of the monocots in July. Lime application caused significant (Table 34) enhancements of protein content (2%) and cellulose content (2%) of *Lespedeza* in July. There were no statistically significant treatment effects on the chemical composition of *Rhus*, composites, or non-*Lespedeza* legumes in the July harvest (Table 34).

Fall harvest. The chemical composition responses of monocots in the Fall harvest was complex, involving significant main effects and numerous significant interactions (Table 34). Cellulose content of the monocots was 3.8% less in samples from plots harvested twice annually than in samples from plots harvested once annually. The hemicellulose and protein proportions were greater in plots harvested twice annually (Table 40). The harvest frequency X lime treatment interaction for cell contents resulted from the different direction of response to the lime treatments in the different harvest treatments (Table 41). Lime application resulted in a significantly greater cell contents proportion for monocots from plots that were harvested twice annually; the lime treatment did not significantly alter the cell contents proportion in plots harvested once annually. Likewise, lime application caused increased ash content in monocots from plots harvested once annually and caused decreased ash content in monocots from plots harvested twice annually. Fertilizer application resulted in increased protein (1.7%) and cell contents (3.8%) at the expense of cellulose (-3.0%) and hemicellulose (-1.6%).

Lespedeza protein was significantly greater in plots harvested twice annually (6.8%) than in plots harvested once annually (4.7%). Lime application resulted in an increase of *Lespedeza* protein from 5.5% without lime application to 7.2% with lime application. The cellulose content of *Rhus* was less in treatments that included fertilizer (29.9%) than in treatments that received no fertilizer (33.5%). None of the

Table 40. Effect of harvest frequency, fertilizer, and lime on the chemical composition (%) of the monocots of an old-field plant community in an abandoned pasture

Chemical parameter	Harvest Frequency			N-P-K Fertilizer ($kg \cdot ha^{-1}$)			Lime ($kg \cdot ha^{-1}$)		
	1	2	Significance[a]	0-0-0	56-56-135	Significance[a]	0	4600	Significance[a]
Cellulose	33.7	29.9	**	33.3	30.3	*	31.3	32.4	NS
Hemicellulose	35.1	39.8	**	38.3	36.7	**	38.1	36.9	*
Lignin	8.2	7.1	NS	7.8	7.5	NS	8.2	7.1	NS
Protein	4.9	6.2	**	4.7	6.4	**	5.5	5.6	NS
Cell contents	14.7	14.6	NS,I	12.8	16.6	**	14.1	15.3	NS,I
Ash	3.4	2.4	**,I	3.2	2.6	NS	2.9	2.9	NS,I

[a]Significance levels are as follows: NS = not significant (P = 0.05); * = significant at 95% confidence level; ** = significant at 99% confidence level; I = a significant interaction with harvest frequency.

Table 41. Combined effects of harvest frequency and lime treatment on the content of selected chemical constituents of the monocot component of an old-field plant community in an abandoned pasture harvested once annually[a]

Harvest frequency	Lime Treatment ($kg \cdot ha^{-1} \cdot yr^{-1}$) 0	1
	Cell Contents (%)	
1	12.6a	13.0a
2	15.6b	17.5c
$LSD_{0.05}$ = 1.8		
	Ash (%)	
1	3.0bc	3.9c
2	2.8ab	1.9a
$LSD_{0.05}$ = 1.0		

[a]The harvest frequency x lime treatment interaction for cell contents and ash were significant at the 95% confidence level (Table 34). Means followed by the same letter were not significantly different based on least significant differences (P = 0.05).

chemical constituents of the miscellaneous composites at the AP site were affected by harvest frequency, fertilizer, or lime in the fall harvest.

Effects of treatments on chemical yields

The mean chemical yields per hectare for all of the treatment combinations for the abandoned pasture site are shown in Table 36. Cellulose yields ranged from 517 $kg \cdot ha^{-1}$ in control treatments harvested twice annually to 2268 $kg \cdot ha^{-1}$ in treatments including NPK fertilizer and lime with one annual harvest. Hemicellulose yields ranged from 477 $kg \cdot ha^{-1}$ in control treatments harvested twice annually to 1610 $kg \cdot ha^{-1}$ in treatments including NPK fertilizer and lime with one harvest annually. Significant treatment effects and interactions for chemical yields were similar to those for biomass yield. Harvest frequency and NPK fertilizer significantly affected the yield of all six of the chemical components for which analysis data were available (Table 37). The yield of chemical components from plots harvested once annually ranged from 34% higher than those harvested twice annually for hemicellulose to 118% higher for ash (Table 42). Likewise, NPK fertilizer also significantly enhanced the yield of each of the chemical components (Table 42). The yield enhancement due to fertilizer application ranged from 65% for lignin to 112% for protein. The yield increase attributable to NPK fertilizer for cellulose, hemicellulose, and ash averaged 90%. Cellulose yield was 80% greater in the single harvest system than in the two-harvest system. Lime caused significant yield increases for each of the chemical components with the exception of protein yield. The magnitude of the increases ranged from 4% for protein (statistically insignificant) to 48% for hemicellulose and lignin. The yield increase attributable to lime application for cellulose and hemicellulose (the chemical components most important to biochemical conversion processes) was 43% and 48%, respectively.

There were also statistically significant harvest frequency x NPK fertilizer interactions for cellulose, cell contents, protein, and ash (Table 37). For each of these chemical components, the yield response

Table 42. Effect of harvest frequency, fertilizer, or lime on the chemical yield ($kg \cdot ha^{-1}$) of vegetation growing on an abandoned pasture in 1987[a]

Component	Harvest frequency		Fertilizer ($kg \cdot ha^{-1} \cdot yr^{-1}$ of N-P-K)		Lime ($kg \cdot ha^{-1}$)	
	1	2	0-0-0	56-56-135	0	4600
Cellulose	1538.3	849.2**	819.5	1568.0**	980.6	1406.9**
Hemicellulose	1110.8	831.5*	669.8	1272.5**	816.8	1125.6**
Lignin	368.9	221.2**	223.3	366.9**	238.4	351.8**
Cell contents	928.0	625.5**	532.5	1021.0**	654.0	899.6*
Protein	301.0	202.4*	161.6	341.8**	247.2	256.2
Ash	155.4	68.1*	76.5	147.0**	93.0	130.5**

[a]*Means significantly different with 95-99% confidence; **Means significantly different with greater than 99% confidence.

to fertilization was significant only in the single-cut system (Table 43).

DISCUSSION

The chemical composition of the successional vegetation was similar to that of herbaceous and wood energy crop candidates (e.g., Bartholic et al. 1983, Blankenhorn et al. 1985, Cherney et al. 1989). The structural carbohydrates (cellulose and hemicellulose) averaged 60% and 52% across all treatments at the AP and AS sites, respectively. The chemical composition of successional vegetation offers no challenges to conversion processes not encountered with other biomass energy feedstock candidates.

Although there were significant effects of fertilizer and lime treatments and harvest dates and frequencies for chemical proportions for individual species and sorting categories, the effects on the chemical composition of the composited mixed-species vegetation were small (the treatments effects varied by <5%). Generally speaking, the fibrous component of individual species increased with maturity. The presence of numerous species with different life cycles and maturities tended to offset one another at any particular point in time, lending stability to the chemical composition of the standing crop during the growing season. The stability of chemical composition of the mixed-species vegetation can be contrasted with the lack of chemical stability characteristic of agricultural systems (annual monocultures) where large shifts in chemical composition occur as the crop matures. In contrast, the chemical composition of old-field vegetation changes markedly during the nongrowing season as decompositional processes preferentially eliminate the compounds that can be most easily degraded (Golley 1965). This results in the increasing lignin proportion during the nongrowing season as the compounds more easily attacked by microbes are metabolized.

The major source of variation in the chemical yield of the successional vegetation was due to the effects of the various treatments on biomass yield. The effects of treatments on chemical proportions of individual species and sorting categories and the treatment effects on

Table 43. Interactive effect[a] of harvest frequency and fertilizer application on chemical yields (kg•ha^{-1}) of old-field vegetation in an abandoned pasture in 1987

	Fertilizer rate (kg•ha^{-1} of N-P-K)	
Harvest frequencyb	0-0-0	56-56-135
	Cellulose[c]	
1	1030.81b	2045.8c
2	608.3a	1090.1b
	Hemicellulose	
1	739.6a	1482.1c
2	600.0a	1063.0b
	Lignin	
1	274.8b	463.1c
2	171.8a	270.7b
	Cell contents[c]	
1	581.1ab	1274.9c
2	484.0a	767.1b
	Protein[c]	
1	166.9a	435.2b
2	156.4a	248.4a
	Ash	
1	102.6b	208.3c
2	50.4a	85.8ab

[a]Means for a chemical component followed by the same letter are not significantly different based on the least significant difference test with 95% confidence. LSD values for cellulose, hemicellulose, lignin, cell contents, protein, and ash equal 332.6, 251.5, 83.9, 269.6, 124.9, and 35.5, respectively.

[b]When harvest frequency was 1, plots were harvested in November 1987; when harvest frequency was 2, plots were harvested in July and November 1988.

[c]Significant harvest frequency*fertilizer interaction (P > 95%) based on analyses of variance.

botanical composition were small compared to the effects of treatments on biomass yield. Therefore, efforts at increasing the yield of individual chemical components important to conversion processes would be more likely to be successful if targeted toward increasing total biomass than toward increasing the proportion of individual chemical or botanical components of the plant community.

INORGANIC CHEMICAL COMPOSITION OF SUCCESSIONAL VEGETATION

INTRODUCTION

Elemental composition influences the suitability of biomass and the economics of its use as an energy feedstock. The ideal biomass energy feedstock would contain only reduced carbon and hydrogen. Presence of other elements, as discussed below, detract from the usefulness or economics of the feedstock. Therefore, maximizing carbon and hydrogen content and minimizing the proportion of all other elements is a goal in selecting crops for feedstock production and conversion processes.

Sulfur and nitrogen in biomass contribute to air pollution when biomass fuels are combusted, and residues from conversion or combustion processes must be disposed of as liquid or solid wastes (Trimble and Van Hook 1984, Smith 1987). Each of these activities increases the cost of using biomass as an energy resource. It is advantageous to minimize the proportions of sulfur and nitrogen in energy feedstock materials (Butner et al. 1988).

The quantity of nutrient elements removed with biomass during harvest impacts the economics of production by influencing the amount of fertilizer that must be applied to soil to maintain adequate levels of nutrients. Nitrogen is often limiting to plant growth, and maintenance of soil nitrogen is a major cost in most crop production systems. Potassium, phosphorous, and to a lesser extent sulfur, are also commonly limiting factors in crop production systems. Calcium and magnesium are applied in lime to satisfy plant requirements and to maintain soil pH within an acceptable range. Removal of these elements should be minimized in order to reduce fertilizer requirements, in addition to avoiding the potential impacts on conversion equipment and waste management charges.

In this section, the content of selected elements from the foliage of the dominant members of the old-field plant communities are presented and the rate of removal from biomass harvesting is calculated. The removal rates are compared to those of other energy crop candidates.

MATERIALS AND METHODS

The dried plant material of the dominant species (those with greater than 100 g) from three blocks from each of the two 1987 harvests were ground to pass through a 40-mesh screen and sent to Rock River Labs (Watertown, WI) and analyzed for the following inorganic constituents reported in ppm: calcium, phosphorous, potassium, magnesium, sodium, sulfur, zinc, manganese, copper, iron, boron, and aluminum (Rock River Labs, Watertown, WI). Chemical yields were calculated based on the average proportion of the elements in the biomass and the biomass yield on a plot-by-plot basis as described in the preceding chapter.

RESULTS

Summary of Results

Due to the complexity of the elemental analysis results, a short overview of results is provided prior to the in-depth presentation. Reference to data tables are omitted from the overview.

Chemical Content

Macronutrients

The November harvest generally resulted in lower chemical foliar concentrations of nitrogen, phosphorous, and potassium than the July harvest at both sites. Calcium concentration was usually higher in November than July. Nitrogen fertilizer at the AS site had no significant effects on macro-nutrient concentrations. Phosphorous fertilizer at the AS site affected only the phosphorous content of monocots, causing it to increase. Fertilizer at the AP site increased potassium content of *Lespedeza* and the content of all macronutrients (N, P, K, Ca, Mg, S) of the monocots but has no significant effect on the macronutrient content of *Rhus*. Lime at the AP site increased N, P, and K content of *Lespedeza* but had no significant effect on *Rhus* or monocot macronutrients.

Micronutrients

The micronutrient response to treatments was generally different from that of the macronutrients. Micronutrient concentrations were usually higher in November than in July. Nitrogen fertilizer at the AS site had little or no effect on the aboveground micronutrient except for causing increased Al and decreased B in monocots. Phosphorous fertilizer effects on micronutrients were limited to an increase of Mn in the monocots. Fertilizer at the AP site caused increased Na and Mn of *Lespedeza*, *Rhus*, and the monocots and caused increased Zn of the monocots and Fe of *Rhus*. Lime caused decreased Mn concentration for *Lespedeza*, *Rhus*, and the monocots.

Elemental Removal

Macronutrients

At the AS site, phosphorous removal was greater and sulfur removal was less in treatments that were harvested twice. Nitrogen fertilizer had no significant effect on macronutrient removal. Phosphorous fertilizer caused increased removal of all of the macronutrients.

At the AP site, the fertilizer treatment combined with the single-harvest treatment usually resulted in increased removal of macronutrients. Lime usually caused increased macronutrient removal regardless of fertilizer treatment or harvest frequency treatment.

Micronutrients

At the AS site, a greater quantity of Fe and B was removed in the single-harvest treatments. Removal of the other micronutrient were unaffected by harvest frequency. Nitrogen fertilizer had no significant effect on micronutrient removal. Phosphorous fertilizer increased Zn, Mn, B, and Al removal.

At the AP site, the removal rate for N, Mn, Cu, Fe, B, and Al was increased by the combined single harvest and nitrogen fertilizer treatments. Zn removal was favored in the two-cut treatment without fertilizer. Lime caused greater removal of all of the micronutrient.

Abandoned Soybean Field

Effect of harvest date

Lespedeza chemical composition was less affected by harvest date than either *Solidago* or the monocots, exhibiting significant harvest date effects for only a few of the minor chemical constituents (Table 44). The manganese, iron, boron, and aluminum contents were significantly greater in the November harvest than in the July harvest. The proportions of N, P, K, Ca, Mg, Na, S, Al, and Cu were not significantly different between July and November harvests. The mean calcium response for *Lespedeza* from the significant harvest date X nitrogen treatment X phosphorous treatment interaction is shown in Table 45. The greatest calcium content occurred in the November harvest in plots that received both nitrogen and phosphorous fertilizer. The smallest calcium content occurred in the same fertilizer treatment in the July harvest. The LSD test indicated no significant differences between the treatment means, casting doubt on the validity of the significance of the interaction as calculated with an F-test.

The effect of harvest date on elemental composition of *Solidago* was significant for most of the chemical parameters that were measured (Table 44). Nitrogen, phosphorous, and potassium content was lower in November than in July. Manganese, copper, iron, and aluminum content was greater in November than in July. There were significant harvest date X nitrogen treatment interactions for potassium and boron for *Solidago* (Table 46). Nitrogen fertilizer significantly reduced the concentration of potassium in July, but in November the nitrogen effect had disappeared. Nitrogen fertilizer had no significant effect on boron in July. In November, boron content of *Solidago* was reduced by nitrogen fertilizer application (Table 46).

In contrast to *Solidago*, the nitrogen and phosphorous content of the monocots was unaffected by harvest date (Table 44). Potassium content of the monocots decreased by 54% between July and November, while the calcium, magnesium, sodium, sulfur, zinc, manganese, copper, iron, boron, and aluminum content increased. There were significant harvest date X nitrogen treatment interactions for calcium, sodium, and boron. Calcium, unaffected by nitrogen fertilizer in July, was significantly reduced by nitrogen fertilizer in November (Table 47). Sodium and boron concentrations, both of which were unaffected by the nitrogen fertilizer treatment in July, were significantly increased by nitrogen fertilizer in November.

Table 44. Effect of harvest date[a] on the elemental composition ($\mu g \cdot g^{-1}$) of the dominant components of old-field vegetation at an abandoned soybean field

	Lespedeza			Solidago			Miscellaneous Monocots		
Element	July	November	Statistical significance[b]	July	November	Statistical significance[b]	July	November	Statistical significance[b]
N	17215	16925	NS	10667	9333	**	10717	10643	NS
P	1526	1573	NS	2589	2074	**	1678	1749	NS
K	8597	7792	NS	22755	14147	**[c]	15496	8388	**
Ca	9389	9359	NS[e]	10427	11049	NS	6311	11530	**[c]
Mg	1990	1784	NS	2526	2224	*	1960	2894	**
Na	455	401	NS	417	416	NS	381	492	*[c]
S	1193	1353	NS	1268	1267	NS	1434	1828	**
Zn	15	15	NS	30	30	NS	27	41	**
Mn	46	70	**	54	78	**	73	128	**
Cu	7	7	NS	8	9	*	6	8	**
Fe	62	106	*	51	95	**	60	187	**[e]
B	15	23	*	31	45	**[c]	12	36	**[c]
Al	31	60	**	38	66	**	42	156	**
Observations	7	12		12	12		12	7	

[a]The November samples include only those harvested once annually.

[b]Statistical significance: NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

[c]Significant harvest date x nitrogen treatment interaction.

[d]Significant harvest date x phosphorous treatment interaction.

[e]Significant harvest date x nitrogen treatment x phosphorous treatment interaction.

Table 45. The combined effects[a] of harvest date, nitrogen treatment, and phosphorous treatment on the iron content of monocots harvested from an abandoned soybean field

	Nitrogen Treatment ($kg \cdot ha^{-1}$)			
	0		87	
Harvest date	Phosphorous Treatment ($kg \cdot ha^{-1}$) 0	111	0	111
	Iron Content of Monocots ($\mu g \cdot g^{-1}$)			
July	62a	67a	52a	59a
November	220c	143b	161b	240c
LSD0.05 = 38				

[a]Means followed by the same letter are not significantly different based on an LSD test with 95% confidence.

Table 46. The combined effects[a] of harvest date and nitrogen treatment on potassium and boron ($\mu g \cdot g^{-1}$) of *Solidago* growing on an abandoned soybean field

Harvest date	Nitrogen Treatment 0	Nitrogen Treatment 1
	Potassium	
July	24204c	21306b
November	14137a	14157a
$LSD_{0.05}$ = 1824		
	Boron	
July	31a	30a
November	52b	39a
$LSD_{0.05}$ = 9		

[a]Means followed by the same letter are not significantly different based on an LSD test with 95% confidence.

Table 47. The combined effect[a] of harvest date and nitrogen fertilizer on the content of calcium, sodium, and boron in monocots from an abandoned soybean field

Harvest Date	Nitrogen Fertilizer Treatment 0	1
	Calcium ($\mu g \cdot g^{-1}$)	
July	6677a	5945a
November	14568c	9251b
$LSD_{0.05}$ = 1253		
	Sodium ($\mu g \cdot g^{-1}$)	
July	415a	348a
November	401a	560b
$LSD_{0.05}$ = 99		
	Boron ($\mu g \cdot g^{-1}$)	
July	12a	12a
November	51c	25b
$LSD_{0.05}$ = 7		

[a]Means followed by the same letter are not significantly different based on an LSD test with 95% confidence.

Effect of harvest frequency

Nitrogen, phosphorous, potassium, calcium, magnesium, sulfur, zinc, manganese, copper, iron, and boron content of *Solidago* was significantly greater in treatments harvested twice than in those harvested once (Table 48). Although there were insufficient samples for analysis of the harvest treatment effect on the chemical composition of *Lespedeza*, the tendency for higher elemental content was qualitatively similar to those for *Solidago* (Table 48).

As was the case for *Solidago* and *Lespedeza*, nitrogen, phosphorous, and potassium content of monocots tended to be greater in the two-cut treatments (Table 48). Unlike *Solidago* and *Lespedeza*, the calcium and sulfur content of monocots was significantly less in the two-cut treatments than in the one-cut treatments. There were significant harvest frequency X nitrogen fertilizer treatment interactions for calcium, sodium, manganese, and boron (Table 49). Calcium and boron responded similarly, with the greatest concentrations in monocots from plots that did not receive nitrogen fertilizer and were harvested once annually. Sodium was greatest in treatments that combined nitrogen fertilizer with two annual harvests, and was least in plots with one annual harvest without nitrogen fertilizer. Manganese was greatest in plots receiving nitrogen fertilizer that were harvested once annually, and least in plots receiving nitrogen fertilizer that were harvested twice annually.

Effect of nitrogen fertilizer

Nitrogen fertilizer did not have a significant effect on the elemental content of *Lespedeza* (Table 50). Since there was insufficient regrowth following the July harvest for chemical analysis of Lespedeza, tests of significance for harvest frequency interactions were not possible. There was a significant nitrogen treatment X phosphorous treatment interaction for sodium, which was greatest in *Lespedeza* from treatments that combined nitrogen and phosphorous fertilizer, and was least in the treatments that included nitrogen fertilizer without phosphorous fertilizer (Table 51).

Table 48. Effect of harvest frequency on the elemental composition ($\mu g \cdot g^{-1}$) of vegetation growing on an abandoned soybean field

	Harvest Frequency								
	Lespedeza			Solidago			Miscellaneous Monocots		
Element	1	2	Statistical significance[a]	1	2	Statistical significance[a]	1	2	Statistical significance[a]
N	16900	22900	-	9300	16200	**	10600	11400	NS
P	1573	2046	-	2074	3605	**	1749	2422	**
K	7792	8961	-	14174	20117	**	8388	11186	**
Ca	9359	11544	-	11049	13572	**	11530	7394	**[b]
Mg	1784	1755	-	2224	3722	**	2894	2495	NS
Na	401	444	-	416	403	NS	492	455	NS[b]
S	1353	1598	-	1237	1944	**	1828	1569	*
Zn	15	17	-	30	39	**	41	42	NS
Mn	70	81	-	78	96	*	128	109	*[b]
Cu	7	8	-	9	12	*	8	8	NS
Fe	106	150	-	95	128	**	187	195	NS[d]
B	23	19	-	45	58	**	36	20	**[b]
Al	60	78	-	66	73	NS	156	138	NS
Observations	12	3		12	10		7	11	

[a]Insufficient sample size for statistical analysis.
[b]Harvest frequency x nitrogen treatment interaction.
[c]Harvest frequency x phosphorous treatment interaction.
[d]Harvest frequency x nitrogen treatment x phosphorous treatment interaction.

Table 49. Combined effect[a] of harvest frequency and nitrogen fertilizer on the content of calcium, sodium, manganese, and boron in monocots from an abandoned soybean field

Harvest frequency	Nitrogen Fertilizer ($kg \cdot ha^{-1}$) 0	87
	Calcium ($\mu g \cdot g$-1)	
1	14568b	9252a
2	7353a	7429b
LSD0.05 = 2168		
	Sodium ($\mu g \cdot g^{-1}$)	
1	401a	560a
2	479ab	435ab
LSD0.05 = 139		
	Manganese ($\mu g \cdot g^{-1}$)	
1	119ab	134b
2	117ab	102a
LSD0.05 = 21		
	Boron ($\mu g \cdot g^{-1}$)	
1	51b	25a
2	18a	22a
LSD0.05 = 11		

[a]Means followed by the same letter are not significantly different according to LSD test with 95% confidence.

Table 50. Effect of nitrogen fertilizer ($kg \cdot ha^{-1}$) on the elemental composition ($\mu g \cdot g^{-1}$) of vegetation growing on an abandoned soybean field (November harvest)

	Lespedeza[a]			Solidago			Miscellaneous Monocots		
Element	0	87	Statistical significance[b]	0	87	Statistical significance[b]	0	87	Statistical significance[b]
N	17600	16200	NS	12300	12600	NS	10700	11400	NS
P	1523	1624	NS	2818	2729	*[d]	2179	2146	NS
K	7660	7923	NS	16216	17398	NS	9257	10771	NS[c]
Ca	8974	9745	NS	12245	12155	NS	10058	8158	*[c]
Mg	1627	1941	NS	2727	3053	NS	2516	2758	NS
Na	401	401	NS[d]	397	421	NS	450	485	NS[c]
S	1360	1345	NS	1563	1554	NS	1633	1699	NS
Zn	15	15	NS	33	35	NS	39	44	NS
Mn	70	70	NS	83	89	NS	118	115	NS[c]
Cu	7	8	NS	10	11	NS	9	8	NS
Fe	116	96	NS	114	106	NS	171	208	NS[e]
B	25	21	NS	54	49	NS	31	23	*[c]
Al	67	53	NS	75	64	NS	124	162	*
Observations	6	6		12	10		8	10	

[a]Only observations from plots harvested once annually are included in this analysis.

[b]Statistical significance: NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

[c]Significant harvest frequency x nitrogen treatment interaction.

[d]Significant nitrogen treatment x phosphorous treatment interaction.

[e]Significant harvest frequency x nitrogen treatment x phosphorous treatment interaction.

Table 51. Combined effect[a] of nitrogen and phosphorous fertilizers on sodium in *Lespedeza* and phosphorous in *Solidago* in an abandoned soybean field

Phosphorous treatment	Nitrogen treatment ($kg \cdot ha^{-1}$)	
	0	87
	Sodium in *Lespedeza*	
0	434ab	324a
1	367ab	478b
LSD0.05 = 144		
	Phosphorous in *Solidago*	
0	2863a	2613a
1	2788a	2846a
LSD0.05 = 294		

[a]Means followed by the same letter are not significantly different based on an LSD test with 95% confidence.

With the exception of a significant nitrogen treatment effect and nitrogen treatment X phosphorous treatment interaction for potassium content, there were no significant nitrogen treatment effects on the elemental composition of *Solidago* (Table 50). The LSD test revealed no significant differences between treatment means for the interaction (Table 51).

Of the elements measured for the monocots, nitrogen fertilizer significantly affected only aluminum content (Table 50). Monocots from plots fertilized with nitrogen exhibited greater aluminum content than those not fertilized with nitrogen. The harvest frequency X nitrogen treatment interactions for potassium, calcium, sodium, manganese, and boron have previously been described.

Effect of phosphorous fertilizer

Phosphorous alone had no significant effect on the elemental composition of *Lespedeza* or *Solidago* (Table 52). The significant interactions shown in Table 52 for *Lespedeza* and *Solidago* have been described in previous sections.

Phosphorous fertilizer significantly increased the phosphorous and manganese content of the monocots (Table 52). The three-way interaction for iron has been previously described.

Elemental yield

The statistical significance of the harvest frequency, nitrogen fertilizer, and phosphorous fertilizer effects and interactions for the calculated elemental yields at the AS site are shown in Table 53. Harvest frequency and phosphorous fertilizer were responsible for most of the variation of elemental yields in this study. Nitrogen fertilizer did not significantly effect the elemental yield of any of the elements that were analyzed. In addition, of the possible interactions, only the harvest frequency X phosphorous treatment interaction for phosphorous was statistically significant (Table 53).

Vegetation from plots harvested once annually exhibited significantly greater sulfur, iron, and boron removal than from plots

Table 52. Effect of phosphorous fertilizer on the elemental composition ($\mu g \cdot g^{-1}$) of vegetation growing on an abandoned soybean field (November harvest)

	Phosphorous Treatment ($kg \cdot ha^{-1}$)								
	Lespedezaa			Solidago			Miscellaneous Monocots		
Element	0	111	Statistical significance	0	111	Statistical significance	0	111	Statistical significance[a]
N	17000	16800	NS	12200	12700	NS	10900	11400	NS
P	1597	1550	NS	2713	2817	NS[c]	1965	2468	*
K	8175	7409	NS	16846	16873	NS	9147	11592	NS
Ca	9482	9237	NS	12031	12333	NS	8562	9695	NS
Mg	1669	1899	NS	2738	3044	NS	2495	2894	NS
Na	379	423	NS[c]	432	392	NS	456	491	NS
S	1388	1317	NS	1552	1564	NS	1625	1739	NS
Zn	16	15	NS	34	34	NS[b]	41	42	NS
Mn	71	69	NS	83	89	NS	111	123	*
Cu	7	8	NS	11	10	NS	8	9	NS
Fe	100	112	NS	110	110	NS	188	198	NS[d]
B	23	23	NS	51	51	NS	24	31	NS
Al	61	59	NS	68	70	NS	140	153	NS
Observations	6	6		10	12		11	7	

[a]Only observations from plots harvested once annually were included in the analysis for Lespedeza.
[b]Significant harvest frequency x phosphorous treatment interaction.
[c]Significant nitrogen treatment x phosphorous treatment interaction.
[d]Significant harvest frequency x nitrogen treatment x phosphorous treatment interaction.

Table 53. Mean square and significance levels[a] for the effects of harvest frequency, nitrogen fertilizer, and phosphorous fertilizer on the elemental yield of old-field vegetation from an abandoned soybean field

Source of variation	df	N	P	K	Ca	Mg	Na	S	Zn	Mn	Cu	Fe	B	Al
		($X10^2$)	($X10^1$)	($X10^2$)	($X10^2$)	($X10^{-1}$)			($X10^{-3}$)	($X10^{-2}$)	($X10^{-4}$)	($X10^{-2}$)	($X10^{-3}$)	($X10^{-2}$)
Block	3	5.7	2.7	4.5	2.1	9.6	3.8	7.6	0.7	0.7	1.1	2.0	2.1	1.3
Harvest frequency (Freq)	1	5.0	16.3**	13.6	1.4	19.5	0.5	18.1*	3.3	1.0	1.1	10.1*	28.6**	1.0
Nitrogen treatment (Ntrt)	1	0.2	0.1	1.2	0.5	5.8	1.8	0.5	0.2	0.1	0.7	0.9	1.6	0.2
Phosphorous treatment (Ptrt)	1	2.0	22.6**	41.9	8.2*	58.3*	9.5	21.6*	8.5**	5.5*	5.9	3.8	18.5**	4.5*
Freq x Ntrt	11	0.8	0.2	<0.1	0.4	4.6	<0.1	0.3	0.3	<0.1	0.1	1.5	0.2	1.0
Freq x Ptrt	1	0.2	10.3**	9.3	0.1	0.6	0.4	3.2	0.6	0.2	<0.1	0.3	0.1	<0.1
Ntrt x Ptrt	1	3.2	1.6	4.2	2.1	6.8	5.8	5.5	0.7	0.6	1.5	2.1	2.4	0.1
Freq x Ntrt x Ptrt	1	6.6	4.6	6.2	3.5	16.3	9.2	9.6	2.6	1.7	2.9	6.8	4.2	1.9
Error	21	2.8	1.2	3.4	1.6	7.4	2.8	4.1	0.9	0.8	1.0	1.8	1.9	0.8

[a]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

harvested twice annually (Table 54). Harvest frequency did not have a significant effect on the other elements that were measured, except for phosphorous which exhibited a significant harvest frequency X phosphorous fertilizer treatment effect. Phosphorous fertilizer significantly increased phosphorous removal from plots harvested twice annually but had no significant effect on phosphorous removal from plots harvested once annually (Table 55).

Phosphorous fertilizer significantly increased the amount of phosphorous, potassium, calcium, magnesium, sulfur, zinc, manganese, boron, and aluminum removed during the harvest of vegetation from the AS site (Table 54). The significant harvest frequency X phosphorous fertilizer interaction for phosphorous has already been described.

Abandoned Pasture

Effect of harvest date

The harvest date at the AP site influenced the elemental composition of the vegetation that was harvested (Table 56). In general, the pattern of response was approximately the same for the dicot (*Lespedeza*, *Rhus*, and the miscellaneous composites) and monocot components. All tended to have higher concentrations of nitrogen, phosphorous, potassium, and magnesium in July than those harvested in November. The opposite was true for calcium and manganese, which were more concentrated in biomass harvested in November than in July. The trace elements Zn, Mn, Cu, and Fe were generally at higher concentrations in biomass harvested during November than in July.

Effect of harvest frequency

The effect of harvest frequency on the elemental composition of vegetation at the AP site was not well defined in this study because the regrowth following the July harvest was often of insufficient quantity for chemical analysis. Only the monocots consistently exhibited adequate regrowth for comparison of the effect of harvest frequency on chemical composition (Table 57). Concentrations of nitrogen, phosphorous, and manganese were greater and concentrations of calcium, magnesium, and manganese were lower in monocots harvested twice.

Table 54. Mean effect of harvest frequency, nitrogen fertilizer, and phosphorous fertilizer on removal of nutrient (kg•ha^{-1}) elements from an abandoned soybean field by harvesting the aboveground biomass in 1987

Element	Harvest Frequency			Nitrogen Fertilizer (kg·ha-1)			Phosphorous Fertilizer (kg·ha^{-1})		
	1	2	Statistical significancea	0	87	Statistical significance[a]	0	111	Statistical significance[a]
N	55.5	64.2	NS	58.7	61.0	NS	56.9	62.7	NS
P	11.5	15.9	**[b]	13.9	13.5	NS	11.1	16.3	**[b]
K	71.2	84.4	NS	75.8	79.8	NS	66.4	89.2	**
Ca	53.4	49.5	NS	50.1	52.8	NS	46.3	56.6	*
Mg	11.0	12.6	NS	11.4	12.3	NS	10.5	13.2	•
Na	2.0	2.1	NS	2.0	2.2	NS	1.9	2.3	NS
S	8.0	6.6	•	7.4	7.2	NS	6.5	8.1	•
Zn	0.12	0.15	NS	0.14	0.13	NS	0.12	0.15	**
Mn	0.40	0.37	NS	0.38	0.39	NS	0.34	0.43	*
Cu	0.04	0.04	NS	0.04	0.04	NS	0.04	0.05	NS
Fe	0.53	0.42	*	0.45	0.49	NS	0.43	0.51	NS
B	0.20	0.14	**	0.16	0.17	NS	0.14	0.19	**
Al	0.36	0.32	NS	0.33	0.35	NS	0.30	0.38	*

[a]NS = not significant; ** = significant with >95% confidence; ** = significant with >99% confidence.
[b]Significant harvest frequency x phosphorous treatment interaction.

Table 55. Combined effect[a] of harvest frequency and phosphorous fertilizer on the foliar phosphorous content ($kg \cdot ha^{-1}$) of vegetation growing at an abandoned soybean field

	Phosphorous Treatment ($kg \cdot ha^{-1}$)	
Harvest frequency	0	87
1	10.8a	12.2a
2	11.5a	20.4b
LSD0.05 = 3.56		

[a]Means followed by the same letter are not significantly different based on an LSD test with 95% confidence.

Table 56. Mean effect of harvest date on the elemental composition ($\mu g \cdot g^{-1}$) of the dominant vegetation at an abandoned pasture in 1987

Element	Misc. legumes[a,b]	Lespedeza			Rhus			Miscellaneous composites			Miscellaneous monocots		
	July	July	November	Statistical significance[c]	July	November	Statistical significance[c]	July	November	Statistical significance[b]	July	November	Statistical significance
N	21100	14450	10840	**	13600	5420	**[f]	10300	7367	•	9992	7800	**[d,f]
P	1548	1113	937	**[e]	1637	937	**[f]	1490	1115	NS	1364	1029	**
K	11962	6335	4496	**[e,f]	10641	5572	**	19120	11910	NS	15019	8684	**
Ca	12118	9854	10505	NS[e]	9833	16605	**	13095	12954	NS	4009	5778	**
Mg	2022	1744	1011	**	1603	1104	**[d]	2008	1842	NS	1699	1666	NS
Na	507	310	550	**	541	563	NS	366	558	NS	364	673	**
S	2318	1112	1132	**	1296	837	**	1485	2028	NS	1458	1443	NS[d]
Zn	26	16	19	•	19	19	NS[e]	31	51	NS	33	48	**[d]
Mn	116	93	149	**[d,e,f]	98	120	NS	131	321	NS	265	362	**
Cu	8	6	8	**	6	7	NS	7	18	NS	5	7	**
Fe	82	54	90	**	73	57	•	51	87	NS	4	10	**
B	22	16	20	**[d]	16	21	**	34	36	NS	6	122	**
Al	30	24	55	**	30	25	NS	41	61	NS	34	66	**
Observations	3	8	10		8	10		2	6				

[a]The miscellaneous legumes were absent in the fall harvest.
[b]Insufficient sample number or distribution for statistical analysis of interactions involving harvest date.
[c]Statistical significance: NS = not significant; • = significant with >95% confidence; ** = significant with >99% confidence.
[d]Significant harvest date x fertilizer treatment interaction.
[e]Significant harvest date x lime treatment interaction.
[f]Significant harvest date x fertilizer treatment x lime treatment interaction.

Table 57. Effect of harvest frequency on the elemental composition ($\mu g \cdot g^{-1}$) of the monocots from an old-field plant community in an abandoned pasture in November 1987

Element	Monocots Harvest Frequency 1	2	Statistical significance[a]
N	7800	9958	**
P	1029	1293	**
K	8684	7901	NS
Ca	5778	4776	*
Mg	1666	1428	*
Na	673	612	NS[b]
S	1443	1421	NS
Zn	48	49	NS
Mn	362	408	*[b]
Cu	7	7	NS
Fe	122	127	NS
B	10	9	NS
Al	66	76	NS
Observations	12	12	

[a]Statistical significance: * - significant with >95% confidence; ** - significant with >99% confidence.

[b]Significant harvest frequency x lime treatment interaction.

Differences in foliar concentrations of the other elements for which data are available were not significant.

Effect of NPK-fertilizer

The mean effects of NPK-fertilizer on the elemental composition of the dominant vegetation, averaged over harvest frequency and lime treatment, are shown for the November harvest in Table 58. The fertilizer treatment X lime treatment interactions shown in Table 58 will be described in the section on lime effects (below).

The elemental composition of the monocots was more sensitive to the fertilizer applications than the dicots. Foliar concentrations of nitrogen, phosphorous, potassium, calcium, magnesium, and sulfur were significantly greater in monocots from plots that were fertilized than in those from plots that were not fertilized (Table 58). Foliar zinc concentrations of monocots were negatively affected by fertilizer.

Foliar concentrations of potassium, sodium, and manganese in *Lespedeza* were enhanced by fertilizer application, and copper concentrations were significantly reduced (Table 58). Sodium and iron concentrations in *Rhus* foliage were positively affected by fertilizer applications.

Effect of lime

The elemental composition of the monocots and *Rhus* was relatively insensitive to the lime treatments, and therefore presumably to soil pH (Table 59). Only foliar zinc and manganese concentrations of the monocots, and only foliar zinc of *Rhus*, were significantly affected by lime application. Zinc and manganese content of the monocots was reduced by lime. Zinc concentration in *Rhus* foliage was increased by lime.

There were significant interactions for sodium (harvest frequency X lime treatment) and manganese (harvest frequency X lime treatment and fertilizer treatment X lime treatment) content in monocot foliage (Table 60). Lime treatment did not significantly affect foliar sodium content of the monocots in plots harvested once and had a positive effect in plots harvested twice. Lime had a greater negative effect on

Table 58. Effect of NPK-fertilizer on the elemental composition ($\mu g \cdot g^{-1}$) of the dominant vegetation components of an old-field plant community at an abandoned pasture in November 1987

	Fertilizer Treatment ($kg \cdot ha^{-1}$ of N-P-K)								
	Lespedeza[a]			Rhus[a]			Monocots		
Element	0-0-0	56-56-135	Statistical significance[b]	0-0-0	56-56-135	Statistical significance[b]	0-0-0	56-56-135	Statistical significance[b]
N	10700	10980	NS	5060	5780	NS	7517	10242	**
P	862	1012	NS	954	921	NS	958	1364	**
K	3615	5376	*[c]	5023	6121	NS	5946	10639	**
Ca	10389	10620	NS	16279	16932	NS	4966	5588	*
Mg	1051	971	NS	1043	1164	NS	1432	1663	*
Na	491	610	*	522	603	*	628	657	NS
S	1162	1101	NS	809	865	NS	1329	1534	**
Zn	21	17	NS	20	19	NS	56	42	**
Mn	111	186	**[c]	108	132	NS	376	394	NS[c]
Cu	9	7	*	7	7	NS	7	7	NS
Fe	88	92	NS	48	66	**	121	128	NS
B	19	21	NS	20	22	NS	9	10	NS
Al	52	58	NS	25	25	NS	71	70	NS
Observations	5	5		5	5		12	12	

[a]There was insufficient regrowth following the July harvest for plots harvested twice for chemical analysis. Therefore, only plots harvested once annually were included in this analysis, eliminating the possibility of analyzing for harvest frequency effects.

[b]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

[c]Significant fertilizer treatment x lime treatment interaction.

Table 59. Effect of lime on the elemental composition ($\mu g \cdot g^{-1}$) of old-field vegetation in an abandoned pasture in November 1987

	Lime Treatment ($kg \cdot ha^{-1}$)								
	Lespedeza[a]			Rhus			Monocots		
Element	0	4600	Statistical significance[b]	0	4600	Statistical significance[b]	0	4600	Statistical significance[b]
N	8800	12200	**	5520	5320	NS	8825	8933	NS
P	823	1013	*	976	898	NS	1157	1165	NS
K	3622	5078	*[c]	5368	5776	NS	8072	8513	NS
Ca	10599	10442	NS	16629	16581	NS	5123	5431	NS
Mg	1041	991	NS	1082	1125	NS	1485	1609	NS
Na	582	529	NS	538	587	NS	650	655	NS[c]
S	1088	1161	NS	813	860	NS	1402	1461	NS
Zn	21	18	NS	17	22	*	52	45	*
Mn	217	103	**[c]	129	111	NS	459	311	**[c,d]
Cu	8	9	NS	6	7	NS	7	7	NS
Fe	89	91	NS	53	61	NS	126	123	NS
B	20	20	NS	21	21	NS	9	10	NS
Al	51	57	NS	25	25	NS	71	70	NS
Observations	4	6		5	5		12	12	

[a]There was insufficient regrowth following the July harvest for plots harvested twice for chemical analysis. Therefore, only plots harvested once annually were included in this analysis, eliminating the possibility of analyzing for harvest frequency effects.

[b]NS - not significant; * - significant with >95% confidence; ** - significant with >99% confidence.

[c]Significant fertilizer treatment x lime treatment interaction.

[d]Significant harvest frequency x lime treatment interaction.

Table 60. Combined effect of harvest frequency and lime on the foliar sodium and manganese content of old-field monocots from an abandoned pasture in November[a]

Harvest treatment	Lime Treatment (kg•ha^{-1}) 0	4600	0	4600
	Sodium		Manganese	
1	717b	629b	416b	309a
2	543a	680b	503c	313a
$LSD_{0.05}$ = 80			$LSD_{0.05}$ = 80	

[a]Means followed by the same letter are not significantly different based on least significant differences (P = 0.05).

manganese content in monocots from plots harvested twice than in plots harvested once. Lime had a greater negative effect on monocot manganese in plots that received fertilizer than in plots that did not receive fertilizer (Table 61).

Lespedeza exhibited significantly greater nitrogen, phosphorous, and potassium concentrations, and lower manganese concentrations, in plots that were limed. There were significant fertilizer treatment X lime treatment interactions for potassium and manganese content for *Lespedeza*. For potassium, the effect of combined fertilizer and lime treatments was synergistic (Table 62). Lime significantly enhanced the manganese content of *Lespedeza* in the absence of NPK-fertilizer but did not have a significant effect on manganese in *Lespedeza* from plots to which fertilizer was applied (Table 62).

Elemental yields

The statistical significance of the harvest frequency, NPK-fertilizer treatment, and lime treatment effects and interactions on elemental yields are shown in Table 63. The harvest frequency, NPK-fertilizer treatment, and lime treatment effects each significantly influenced the removal of all of the elements that were measured, with the exception of the harvest frequency effect on nitrogen and the lime treatment effect on manganese.

The harvest frequency X NPK-fertilizer treatment effect was significant for each of the measured elements except for nitrogen, phosphorous, and zinc (Table 63). The pattern of response to harvest frequency and NPK-fertilizer was similar for all elements, regardless of the significance of the interaction (Table 64). The NPK-fertilizer approximately doubled the yield of each element in the one-cut treatments. The NPK-fertilizer effect was smaller in the two-cut treatments.

The removal of the measured elements (with the exception of Mn) was significantly increased by lime (Table 65). The enhancement of elemental removal averaged approximately 40%, an amount similar to the lime effect on yield in 1987.

Table 61. Combined effect of fertilizer and lime on the manganese content ($\mu g \cdot g^{-1}$) of old-field monocots from an abandoned pasture

Lime treatment ($kg \cdot ha^{-1}$)	Fertilizer Treatment ($kg \cdot ha^{-1}$ N-P-K)	
	0-0-0	56-56-135
0	421b	497c
4600	322a	291a
LSD0.05 = 47		

[a]Means followed by the same letter are not significantly different based on least significant differences (P = 0.05).

Table 62. Combined effect of fertilizer and lime on the potassium and manganese content ($\mu g \cdot g^{-1}$) of *Lespedeza* from an abandoned pasture[a]

Lime treatment ($kg \cdot ha^{-1}$)	Fertilizer Treatment ($kg \cdot ha^{-1}$ of N-P-K) 0-0-0	56-56-135
	Potassium	
0	3608a	3636a
4600	3620a	6536b
LSD0.05 = 1754		
	Manganese	
0	145a	89a
4600	289b	117a
LSD0.05 = 41		

[a]Means followed by the same letter are not significantly different according to least significant differences (P > 0.05).

Table 63. Mean square and significance levels[a] for the effects of harvest frequency, fertilizer, and lime on the elemental yield of old-field vegetation from an abandoned pasture

Source of variation	df	N	P	K	Ca	Mg	Na	S	Zn	Mn	Cu	Fe	B	Al
		($\times10^{1}$)		($\times10^{1}$)	($\times10^{1}$)				($\times10^{-2}$)	($\times10^{-1}$)	($\times10^{-3}$)	($\times10^{-2}$)	($\times10^{-3}$)	($\times10^{-2}$)
Block	3	1.5	0.1	5.2	4.3	0.3	0.1	0.8	0.1	0.5	0.1	0.2	0.3	0.1
Harvest frequency (Freq)	1	6.3	7.3*	386.3**	385.4**	43.5**	16.0**	70.1**	7.2**	44.5**	7.5**	43.2**	25.8**	17.0**
Fertilizer treatment (Ftrt)	1	323.1**	78.8**	405.5**	254.4**	117.8**	12.5**	97.0**	3.8**	31.9**	3.3**	34.0**	10.7**	10.9**
Lime treatment (Ltrt)	1	169.4**	16.5**	83.7**	103.8**	30.7	2.7**	30.4**	1.1*	0.3	1.1**	9.7**	4.9**	3.4**
Freq x Ftrt	1	23.2	2.3	139.1**	74.9*	13.7	3.0**	16.1*	0.4	6.8**	1.1**	7.5**	4.3**	2.5**
Freq x Ltrt	1	0.3	0.4	10.6	10.4	0.9	0.1	1.8	0.1	0.2	0.2	1.1	1.1	0.6
Ftrt x Ltrt	1	0.3	0.3	6.0	0.1	0.1	<0.1	0.7	>0.1	0.3	>0.1	0.1	>0.1	0.1
Freq x Ftrt x Ltrt	1	1.4	1.0	2.7	9.5	0.9	0.5	2.6	>0.1	1.6	0.3	0.8	0.7	0.4
Error	21	8.4	1.2	8.6	10.7	2.9	0.3	2.6	0.2	0.7	0.2	0.7	0.6	0.3

[a] * = significant with >95% confidence; ** = significant with >99% confidence.

Table 64. Combined effect[a] of harvest frequency and fertilizer treatments on element removal ($kg \cdot ha^{-1}$) from an abandoned pasture by harvesting the aboveground biomass in 1987

Harvest frequency	Fertilizer Treatment[b] 0-0-0	56-56-135
	Nitrogen	
1	22.6a	48.1b
2	25.2a	39.9b
$LSD_{0.05}$ = 9.6		
	Phosphorous	
1	2.8a	6.5c
2	2.4a	5.0b
$LSD_{0.05}$ = 1.1		
	Potassium	
1	22.6a	58.3b
2	13.8a	23.2a
$LSD_{0.05}$ = 9.6		
	Calcium	
1	28.9b	56.5c
2	17.8a	24.8ab
$LSD_{0.05}$ = 16.7		
	Magnesium	
1	4.45ab	9.60c
2	3.43a	5.96b
$LSD_{0.05}$ = 1.77		
	Sodium	
1	1.69b	3.55c
2	0.89a	1.53b
$LSD_{0.05}$ = 0.52		
	Sulfur	
1	4.44ab	9.34c
2	2.90a	4.96b
$LSD_{0.05}$ = 1.66		

Harvest frequency	Fertilizer Treatment[b] 0-0-0	56-56-135
		Zinc
1	0.13a	0.23b
2	0.62c	0.11a
$LSD_{0.05}$ = 9.6		
		Manganese
1	0.82b	1.75c
2	0.37a	0.71b
$LSD_{0.05}$ = 0.28		
		Copper
1	0.03b	0.06c
2	0.01a	0.02ab
$LSD_{0.05}$ = 0.013		
		Iron
1	0.29b	0.59c
2	0.15a	0.26b
	$LSD_{0.05}$ = 0.09	
		Boron
1	0.06b	0.12c
2	0.03a	0.04a
	$LSD_{0.05}$ = 0.025	
		Aluminum
1	0.18b	0.34c
2	0.08a	0.14b
	$LSD_{0.05}$ = 0.05	

[a]Means followed by the same letter are not significantly different according to an LSD test with 95% confidence.

[b]Fertilizer treatments included application of either 0-0-0 or 56-56-135 $kg \cdot ha^{-1}$ of N-P-K, respectively.

Table 65. Mean effect of lime on the removal of nutrient elements ($kg \cdot ha^{-1}$) from an abandoned pasture by aboveground harvesting in 1987

	Lime Treatment ($kg \cdot ha^{-1}$)		
Element	0	4600	Statistical significance[a]
N	26.6	41.2	**
P	3.5	4.9	**
K	24.4	34.6	**
Ca	26.0	37.4	**
Mg	4.9	6.8	**
Na	1.6	2.2	**
S	4.4	6.4	**
Zn	0.11	0.15	**
Mn	0.88	0.94	NS
Cu	0.03	0.04	*
Fe	0.27	0.38	**
B	0.05	0.08	*
Al	0.15	0.22	**

[a]NS = not significant; * = significant with >95% confidence; ** = significant with >99% confidence.

DISCUSSION

The elemental composition of biomass is an important characteristic for energy feedstock considerations for three reasons: chemical suitability as a feedstock material, waste disposal and air pollution, and as an estimator of the soil amendments required to maintain site productivity.

In addition to the organic chemical criteria for feedstock suitability discussed in a previous section, the inorganic component can also influence the suitability of biomass as an energy feedstock. The inorganic fraction is the major contributor of ash residue and reactor vessel fouling in combustion and gasification systems, as well as a component of waste sludge and potential toxicity in biological systems (Butner et al. 1988).

Since the mineral content of the old-field biomass was unaffected by lime or fertilizer applications, moderate soil amendments that increase yield are unlikely to increase reactor vessel scale or waste disposal processes. Rates of fertilization greater than those used in the present experiments could increase foliar mineral content (Wedin 1974). Biomass from the AS site had a greater mineral element content (as opposed to mineral mass) than the AP site. This could have been due to differences in maturity of the species present at the time of harvest or to differences in soil conditions, e.g., pH). Harvest frequency also affected mineral content. Different interactions of site, successional stage, harvest frequency, and meteorological factors will probably affect mineral compositions in ways that are largely uncontrollable by a producer.

Nitrogen and sulfur in old-field biomass are similar to those characteristic of other energy feedstock candidates. In species screening trials at Vickery, Ohio, reported by Turhollow et al. (1990), warm-season grasses exhibited smaller nitrogen content (0.5% to 0.7%) than the old-field biomass from the present study. The cool-season grasses and legumes in the Vickery, Ohio, study exhibited higher nitrogen contents (1.3% to 2.9%) than old-field biomass (0.8% to 1.2%). The differences between the warm- and cool-season crops are probably due to differences in metabolism (C4 vs C3) and maturity at harvest. During senescence, plants transport nitrogen from foliage to storage organs, which usually are seeds for annuals or underground stems or roots for perennial nonwoody plants. In the Vickery, Ohio, study, samples for nitrogen analysis were collected during the fall, after senescence of the warm-season species but during an active growth phase of the cool-season species. That probably contributed to the difference in nitrogen content. Old-field communities include warm- and cool-season species resulting in nonsynchronous growth and smaller fluctuations in chemical content of the biomass than would be expected in monocultural crops. The nitrogen content of old-field biomass in conditions of moderate fertility is a function of botanical composition and harvest date. In highly fertile or heavily fertilizer sites, nitrogen content may increase.

Sulfur content in old-field biomass was unaffected by fertilizer, lime, harvest frequency, or site in the present study, ranging between 0.1% and 0.2%. The warm- and cool-season species used in the Vickery, Ohio, screening trial exhibited a range of sulfur contents from 0.09% to 0.25%. It is unlikely that nitrogen and sulfur pollution will impose serious challenges on the use of old-field biomass as an energy feedstock material.

Nutrient removal from the fields where energy crops are grown must be replaced in order to maintain productivity. In the present study, nutrient elements in the harvested biomass represented a constant proportion of the total harvested biomass. The treatments that encouraged greater levels of productivity did not cause increases in the proportion of nutrient content. The nutrient removal rate for nitrogen, phosphorous, and potassium averaged 1.1%, 0.2%, and 1.1%, respectively, of the total biomass harvested. The harvested biomass at the two sites had equal nitrogen contents, but phosphorous and potassium content of the AS biomass was 1.8 and 1.5 times higher than that of the AP. Knowledge of soil mineralization, leaching, immobilization, precipitation inputs, and biomass removal would allow the calculation of maintenance fertilization rates. Old-field vegetation is relatively efficient in its use of nutrient elements, and replenishment of soil nutrients to make up for those removed during harvesting is not expected to have a large impact on the production economics of old-field biomass for energy.

The elemental content of old-field vegetation was within the range represented by annual (Marten and Andersen 1975) and perennial (Marten et al. 1987) weed species grown in monoculture; forage crops (Wedin 1974, Wilkinson and Langdale 1974); and monocultural energy feedstock candidates Turhollow et al. 1990). There are no apparent chemical constraints for use of old-field biomass as an energy feedstock additional to those recognized for other energy crops.

EFFECT OF BIOMASS REMOVAL ON SOIL NUTRIENT STATUS AND NUTRIENT DEPLETION ON TWO OLD-FIELD PLANT COMMUNITIES

INTRODUCTION

One of the environmental issues commonly raised during considerations of the feasibility of using biomass as an energy feedstock is soil degradation by depletion of soil nutrient pools and soil erosion (Pimental et al. 1984). These arguments are well founded for crops requiring annual or regular soil disturbance and whose chemical composition has been selected to include a broad array of nutrients for use by animals for feed. This includes carbohydrate crops such as corn, small grains, and sugar beets, and protein and oilseed crops such as soybean and peanuts. Perennial forage crops and native vegetation do not require regular soil disturbances and their inherently low nutrient composition is an advantageous energy crop characteristic, because the presence of those substances can be detrimental to conversion processes (Butner et al. 1988) and would unnecessarily contribute to soil depletion of nutrient elements.

In the present study, soil samples were collected annually in order to track any changes in soil chemistry in the different treatments during the 3-year duration of this experiment.

MATERIALS AND METHODS

The overall design of the experiment was discussed in an earlier chapter, which should be consulted for reference. Soils were sampled according to the schedule shown in Table 3 by collecting three soil cores from a transect across the middle of each plot. The samples were collected from the A horizon to a depth of 15 to 20 cm. The three cores were thoroughly mixed, packaged in plastic bags, and sent to A&L Agricultural Laboratories (Memphis, TN) for analysis. The following analyses were performed: cation exchange capacity (CEC), Ph, organic matter (%), nitrate concentration (ppm; 1987 and 1988 only), and elemental analysis (ppm) of potassium, phosphorous, calcium, and magnesium. The results of the chemical analyses were subjected to analysis of variance to determine the effects of the various fertilizer, lime, and harvest frequency effects on soil nutrient pools for each year individually.

RESULTS

Treatment effects on soil chemistry were determined for 1987 and 1988 separately with analysis of variance. Due to unexplained high levels of variance among the 1987 samples, only those analyses for 1988 are presented.

Soybean Site

Among the main effects, phosphorous fertilizer and harvest frequency had significant effects on soil phosphorous and soil nitrate concentrations, respectively (Table 66). There were no significant effects of nitrogen fertilizer treatments on soil chemistry at the AS site. Soil nitrate concentrations were not affected by nitrogen fertilizer application. Phosphorous fertilization increased soil phosphorous concentration from 4.6 ppm in plots receiving no phosphorous fertilizer to 6.3 ppm in plots receiving phosphorous fertilizer. Harvest freque affected soil nitrate concentrations. Plots harvested twice annually averaged 12.7 ppm of nitrate, significantly higher than those harvested once annually (7.9 ppm). Organic matter tended to be highest in treatments including one annual harvest without nitrogen fertilizer (2.3%) and lowest in treatments including one annual harvest with nitrogen fertilizer (1.9%), with plots harvested twice annually intermediate in organic matter concentration (2.1%). CEC and $[H^+]$ exhibited statistically significant interaction between harvest frequency, nitrogen fertilizer, and phosphorous fertilizer (Table 66). Treatments including nitrogen fertilizer tended to exhibit a higher CEC and $[H^+]$ than those not receiving nitrogen fertilizer, regardless of phosphorous fertilizer or harvest frequency treatments. This generalization held true except for those plots harvested twice annually and receiving phosphorous fertilizer, where the reverse was true. The treatment means for CEC did not vary over 5% from their overall mean, and the $[H^+]$ effect amounted to less then 0.3 pH units difference, so the short-term biological significance of these effects are probably

Table 66. Mean square and significance levels[a] of the effects of harvest frequency, fertilizer, and lime on soil chemistry of old-field plots in 1988

Source of variation	Degrees of freedom	Phosphorous	Potassium	Magnesium	Calcium	Nitrate	Organic matter	CEC	$[H^+]$
				$(X10^{-1})$	$(X10^{-2})$	$(X10^{-1})$	$(X10^{1})$	$(X10^{1})$	$(X10^{1})$
Abandoned Soybean Field									
Block	3	4.71	10.04	14.50	48.86	5.01	0.51	6.56**	0.81
Harvest frequency (Freq)	1	0.13	36.13	47.28	11.28	18.53*	0.15	0.01	0.23
Nitrogen treatment (Ntrt)	1	0.50	36.13	16.53	34.03	2.78	2.28	0.61	0.19
Phosphorous treatment (Ptrt)	1	24.50**	91.13	21.53	30.03	0.38	3.40	0.31	0.28
Freq * Ntrt	1	2.00	6.13	2.63	87.78	2.63	3.40	4.05	0.12
Freq * Ptrt	1	2.00	0.13	149.88	87.78	0.53	9.45*	0.20	2.86*
Ntrt * Ptrt	1	1.13	0.13	0.08	0.28	3.83	>0.01	0.05	>0.01
Freq * Ntrt * Ptrt	1	15.13	28.13	53.63	16.53	15.75	7.50*	4.51*	5.43*
Error	21	3.83	30.80	38.51	36.55	4.28	1.75	0.97	0.43
Abandoned Pasture									
Block	3	0.86	99.97*	4.14	45.64	1.22*	1.23	0.33	0.93
Harvest frequency (Freq)	1	0.43	118.31*	2.77	2.17	>0.01	1.07	0.57	0.58
Lime treatment (Ltrt)	1	3.31	379.62**	5.59	13324.68**	6.37*	0.67	150.24**	13.64**
Fertilizer treatment (Ftrt)	1	27.72*	6273.93**	4.93	2.91	0.09	0.01	0.44	0.90
Freq * Ltrt	1	0.11	124.43*	10.64	10.56	0.43	>0.01	0.61	0.01
Freq * Ftrt	1	0.12	64.83	0.04	49.26	0.58	0.03	0.12	3.51*
Ltrt * Ftrt	1	2.05	77.94	0.77	78.36	0.17	0.40	2.81	0.30
Freq * Ltrt * Ftrt	1	>0.01	41.18	14.79*	24.21	>0.00	0.14	4.05*	0.16
Error	21	2.34	28.38	3.48	23.99	0.37	1.60	0.66	0.54

[a]* = significant with >95% confidence; ** = significant with >99% confidence.

minor. Over several decades, the interactive effects of nitrogen and phosphorous fertilization, and harvest frequency on CEC and $[H^+]$ could take on greater significance if the tendencies continue or accelerate.

Pasture Site

There were significant effects of harvest frequency, lime treatment, and fertilizer treatment on all soil chemical parameters measured except for magnesium concentration and CEC at the AP site (Table 66). The effect of harvest frequency was statistically significant for potassium concentration, where plots harvested once annually averaged 104 ppm versus those harvested twice annually averaging 100 ppm. Significant enhancements due to lime application averaged 7%, 73%, 22%, and 16% for potassium, calcium, nitrate and CEC, respectively. Plots receiving lime averaged 0.6 pH units higher than those receiving no lime (5.26 vs 5.87). Fertilizer application significantly increased potassium (7%) and phosphorous (157%) concentrations, but did not significantly affect nitrate concentrations.

In addition, there were several statistically significant interactions between harvest frequency, lime treatment, and fertilizer treatment (Table 66). There was a significant harvest frequency X lime treatment interaction for soil potassium concentration. Potassium concentration was significantly greater in plots harvested once annually without lime additions than in plots harvested once annually with lime application or those plots harvested twice annually regardless of lime treatment. Due to the rather small treatment mean differences, the biological significance of this interaction is probably minor in the short term. Soil acidity exhibited a significant interactive response to harvest frequency and fertilizer. Soil pH was lower in treatments that included fertilizer application and one annual harvest than in treatments harvested once annually that did not receive fertilizer applications or treatments harvested twice annually, regardless of fertilizer treatment. In this case, treatments that encouraged high biomass productivity also caused decreased soil pH. Both magnesium concentration and CEC exhibited significant harvest frequency X lime treatment X fertilizer treatment interactions. Plots harvested once annually that received lime tended to have lower magnesium concentrations (91.3 ppm) than those harvested annually without lime application (97.8 ppm), or those harvested twice annually regardless of lime treatment (98.3 ppm). CEC tended to be higher in treatments receiving lime and harvested twice annually, but the differences between means were small (although occasionally statistically significant) and probably biologically insignificant in the short term.

DISCUSSION

The results of the soil chemistry analyses demonstrate the ephemeral nature of nitrogen fertilizers applied to the soil. From applications made during the spring and summer months, the nitrogen (measured as nitrate) had disappeared from the soil solution by the following spring. Nitrogen removal with the harvested biomass averaged 60 $kg \cdot ha^{-1}$ at the AS site and was not affected by the nitrogen fertilizer treatment. At the AP site, nitrogen removal averaged 44 $kg \cdot ha^{-1}$ in fertilized plots, 1.8 times the amount removed from unfertilized plots. The nitrogen lost to the system via biomass harvest, ground water leaching, and volatilization would require replacement by fertilizer-nitrogen to sustain productivity of the systems. Maintenance nitrogen applications must take into account removal processes such as leaching and volatilization, as well as inputs by rain. If rainfall nitrogen balances the losses due to volatilization and leaching, a maintenance nitrogen application rate can be calculated from the biomass removal rate. Nitrogen inputs to the system by rain and dry deposition measured at a site less than 0.5 km distant from the old-field plots indicates annual input of an average of 9.3 $kg \cdot ha^{-1} \cdot yr^{-1}$ over the period 4/86 through 3/88 (Lindberg and Johnson 1988).

Lime application at the AP site increased soil pH, an effect that should persist for several years. The increased soil phosphorous concentration should also persist for several years since it is slowly released in the soil due to strong attraction to soil particles. The increase of potassium content due to fertilizer application was smaller than that of phosphorous. Potassium is more highly soluble than phosphorous and is thus more mobile and more easily removed from the system by leaching into the soil profile.

After 3 years of biomass removal, there were no signs of depletion of the pools for the major or minor plant nutrients in the treatments that received no lime or fertilizer at either site. In addition, removal of nutrient elements with biomass harvests were such that replacement rates for fertilizers is low. It was evident that liming would occasionally be necessary at both sites in order to maintain acceptable soil pH levels.

ECONOMICS OF PRODUCING OLD-FIELD VEGETATION

INTRODUCTION

The previous chapters have demonstrated that old-field vegetation produced as a low-input crop can compete in terms of yield with the other perennial crops under consideration as energy feedstock candidates. Some of the annual crops under consideration, such as *Sorghum bicolor*, exhibit higher yields under good growing conditions but are also more prone to erosion and are riskier due to the higher input costs of annual establishment, requirement for higher levels of fertilizer, and the potential for crop failures due to drought or flooding. Qualitatively, mixed-species, old-field vegetation may be less productive than other energy crop candidates in terms of yield, but in terms of economics and risk this type of crop may be a viable competitor.

In this chapter a simple economic analysis is used to estimate the costs of producing old-field vegetation.

MATERIALS AND METHODS

Production costs were based on fertilizer and lime application rates (see Table 2), interest on capital, overhead, and harvesting costs (Table 67). Application charges were included in the costs for fertilizers and lime, and all labor and equipment charges were included in the harvesting rate. Therefore, there were no separate charges for equipment or labor in these production cost estimates. These estimates represent the minimum investment that a landowner could make to produce a crop. The production cost estimates presented are independent of any charges attributable to the cost of owning or renting land.

RESULTS AND DISCUSSION

The calculated production costs are presented in Table 68. Yield increases in response to fertilizer and/or lime applications were insufficient to offset the costs of application, resulting in the lowest production costs in the control treatments. Production costs in

Table 67. Charges for materials and services used in calculation of crop production costs[a]

Cost Category	Rate
Fertilizer	
Nitrogen	\$0.57/kg
Phosphorous	\$0.53/kg
Potassium	\$0.35/kg
Lime	\$22.05/Mg
Interest on fertilizer and lime expense	12%
Overhead	7%
Harvesting charges[b]	\$10 per Mg of biomass

[a]These costs are based on charges used by the Alabama Agricultural Extension Service in estimating the costs of producing forage crops in 1988 (Bransby, personal communication).

[b]Includes mowing, windrowing, and baling (large round bales).

Table 68. Estimated cost of production per Mg of biomass[a]

Treatment: Harvest frequency	Fertilizer ($kg \cdot ha^{-1}$): N	Fertilizer ($kg \cdot ha^{-1}$): P	Production cost ($): 1986 per Mg	Production cost ($): 1987 per Mg	Production cost ($): 1988 per Mg	3-year average ($\$ \cdot Mg$-1)	3-year average yield ($Mg \cdot ha^{-1}$)
			Abandoned Soybean Field				
1	0	0	10	10	10	10	4685
1	87	0	25	24	18	22	5348
1	0	111	28	24	20	24	5267
1	87	111	42	30	25	32	6364
2	0	0	10	10	10	10	5245
2	87	0	27	21	17	22	6022
2	0	111	29	24	18	24	5660
2	87	111	43	33	29	35	5490

Treatment: Harvest frequency	NPK fertilizer	Lime	Production cost ($): 1986 per Mg	Production cost ($): 1987 per Mg	Production cost ($): 1988 per Mg	3-year average ($\$ \cdot Mg^{-1}$)	3-year average yield ($Mg \cdot ha^{-1}$)
			Abandoned Pasture				
1	0-0-0	0	10	10	10	10	2666
1	56-56-135	0	49	36	32	39	3453
1	0-0-0	4600	44	41	40	42	4426
1	56-56-135	4600	76	49	53	59	4778
2	0-0-0	0	10	10	10	10	3111
2	56-56-135	0	38	54	29	40	3855
2	0-0-0	4600	36	55	38	43	5069
2	56-56-135	4600	62	67	49	59	5226

[a]Cost estimates are independent of land charges.

treatments that included fertilizer or lime applications were lower at the abandoned soybean field, where yield stimulations were sufficient to partially offset the cost of applications. Production costs were lower in 1988, when late-season rainfall contributed to greater yields which helped to offset fertilizer and lime charges. No guidelines concerning the optimal fertilization levels were available when this experiment was initiated. Different application rates for some of the fertilizers could have substantially improved on the economics of production. For instance, elimination of the potassium from the fertilizer applied to the pasture site would probably not have a large effect on productivity. Therefore, its elimination would have improved the economics for that site. Also, in the budgets reported here, the cost of lime applied to the AP was not prorated, as is the practice in most crop budgeting estimates. Although lime was applied in each of the 3 years of this experiment, its activity is long-lasting, and once a desired soil pH is attained, liming intervals are usually increased to 5 or more years. The greater yields at the AS were probably partially due to the lime inputs from the earlier soybean crops. Therefore, the earlier soybean cropping effort subsidized the production cost of the old-field vegetation by residual soil improvements.

Compared with production costs for other crops under consideration as energy feedstocks, old-field vegetation offers a low-cost alternative (David Bransby, personal communication; Cherney et al. 1989). Cherney et al. (1989) reported production costs ranging between $40 and $58 per Mg for switchgrass (*Panicum virgatum*) and sorghum-sudangrass (*Sorghum bicolor* X *sudanense*), respectively. Their production budgets included costs for land, storage, and transportation, which were not accounted for in the present experiment. Since only marginal agricultural land is required by old-field vegetation, land costs would be expected to be minimal (A. F. Turhollow, personal communication). The costs of production are minimal due to the lack of any charges for establishment or cultivation. However, the low cost of production must be balanced against the low rate of production, which in analyses that include land and transportation costs will tend to work against low yielding crops.

Old-field vegetation offers a low input, low cost, low risk alternative for energy feedstock production. Selection of optimal harvest dates would improve the economics of production considerably, as would optimization of the low levels of soil amendments required to sustain productivity. Since this experiment was conducted during the most prolonged drought on record for the southeastern United States, yields should be significantly higher in years with greater amounts of rain. This would result in higher levels of productivity that would have positive influences on production costs.

CONCLUSIONS

Old-field vegetation offers a low input, low risk alternative for the production of lignocellulosic energy feedstock materials. Levels of productivity in this report indicate that successional vegetation during the unusually dry conditions of 1986-1988 were generally as productive as the perennial, monocultural energy crops established in the southeastern United States during the same years (Turhollow 1988, Cushman et al. 1989). Only switchgrass (*Panicum virgatum*) consistently exhibited yields higher than those reported for old-field vegetation in this study. The chemical composition of successional vegetation offers no known conversion constraints additional to those for other energy feedstocks. Successional vegetation was also shown in this report to be responsive to the addition of soil amendments, such as fertilizers and lime, although to a lesser extent than some other energy crop candidates such as sweet sorghum and switchgrass. Because the optimal fertilization and liming rates were not established in these experiments, additional research will be required to establish the production potential of successional vegetation and the cost-effectiveness of fertilizer inputs to achieve optimal production levels. Infrequent harvests required by successional vegetation for maximum productivity reduce the costs attributable to harvesting, and the broad window of satisfactory harvesting (76% of the total biomass was already present in July) times reduce the need for storage.

Additional advantages of using old-field vegetation as an energy feedstock include agricultural and environmental considerations. Successional species automatically invade agricultural lands that have lapsed into periods without maintenance. Therefore, there is minimal risk of establishment failure. This contrasts with the annual risks associated with high-yielding annual crops. Ground cover on abandoned agricultural cropland is rapidly established, reducing the risk of loss of site productivity and environmental degradation due to soil erosion. All sites suitable for agricultural production, and many that are not suitable, will sustain robust successional plant communities capable of producing significant quantities of lignocellulosic biomass. The genetic diversity of a successional plant community provides a buffering capacity against environmental stresses and biological pests, such as extremes of temperature or drought, and insect and disease attack. The loss of one or more species to biotic or abiotic stress factors is likely to be compensated by other members of the community.

There are also disadvantages associated with the use of successional vegetation as an energy feedstock. It is unlikely that successional vegetation can be manipulated to provide the yields that are possible with annual or perennial monocultures that are bred specifically for energy feedstock production. Therefore, even though the costs associated with production may be lower for successional vegetation than for monocultural crops, the lower yield would require more land to sustain equal levels of production, and transportation costs caused by the requirement for additional land could become prohibitive. An economic assessment of the production and delivery cost for biomass will be required before these relationships can be defined. There is also a possibility that the conversion processes now under development will ultimately require that feedstock chemistry fall within a restrictive range that will be difficult for a multispecies crop to satisfy.

In summary, this research effort has established that old-field vegetation is sufficiently productive and chemically suitable to warrant consideration as a contributing source of feedstock material for conversion to energy. Old-field vegetation responds positively to low inputs of fertilizer and lime, although not economically in the present effort, and the chemical yield of the mixed-species vegetation is more a function of the total level of productivity than the cultivation methods or fertilizer inputs that were used.

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