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Screening and Selection of Herbaceous Species for Biomass Production in the Midwest/Lake States Final Report 1985–1989

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SCREENING AND SELECTION OF HERBACEOUS SPECIES FOR BIOMASS PRODUCTION IN THE MIDWEST/LAKE STATES

Final Report 1985-1989

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ABSTRACT

Three tasks were undertaken to evaluate the production of biomass in the Midwest/Lake States. The first task was the development of a soil resource inventory using an automated soil data base and digitized soil maps. The study demonstrates how an automated soil data storage, retrieval, and display system can be used to predict soil related problems, to identify areas most suitable for biomass production, and to provide soil data for use in crop simulation models.

A second task involved both field and laboratory (NDF, ADF, ADL, Kjeldahl nitrogen, and dry ashing) experiments. Fertility levels and harvest management systems were evaluated for several species on a variety of soil types to ascertain their suitability for production of biomass for conversion to energy.

The final task was to develop a computer program to model biomass production. Data was collected and a program (HERBIE) which requires weather, soil survey, soil test, and management data as inputs has been designed. Growth parameters for biomass crops will be part of the model. Outputs will be estimates of biomass yield, including growth curves as a function of time.

OVERVIEW OF PROJECT

This project was divided into three tasks. The first task was to develop a soil resource inventory to identify soils with potential for use in biomass production. The entire work is available in a thesis (Hanford, 1987) and is also on file at Oak Ridge National Laboratory. A summary of the work is included in Section I.

Section II describes the second phase of the project, the overall objective of which was to identify plant species that produce large quantities of harvestable biomass suitable for energy production and that are adapted to the soils and climate of the Midwest/Lake States of the United States. Nine sites with various limitations for crop production were chosen for field research. Several crops were tested at each site under different harvest management systems and levels of fertility. Selected harvested samples were analyzed for fiber, ash, and total nitrogen content, as these seem to be important factors affecting the ease of conversion of biomass to energy.

The task discussed in Section III was to develop a simple computer simulation model to predict biomass yields under a variety of crop, soil, weather, and management situations. It involved two subprojects. The first was to collect the kind of data for several potential biomass crops that would be helpful in model formulation and testing. The second was to actually develop and test the model.

I. SOIL RESOURCE INVENTORY

SUMMARY OF WORK

An automated soil data base and digitized soil maps were used to inventory existing soil characteristics which affect forage growth and to determine where areas of marginal farmland exist which might be used for biomass production. The areas where these suboptimal conditions exist and areas of prime farmland are shown by the resource inventory. The study included the Northeast and the Lake States regions of the United States.

The soils occurring on the base map legends are divided into technical groups. These groups are based on the soil characteristics and soil suitability for forage growth. The soil characteristics used for making the technical groupings include the following: soil drainage, flooding hazard, pH, depth, texture, available water-holding capacity, rock fragments, overall farmland quality, erosion potential, soil temperature regime, and crop adaptability. The results of this inventory were output in three formats: 1) a computer data table containing soil characteristics, 2) tables showing technical grouping of the soils, and 3) digitized interpretive soil maps identifying soil characteristics and locating areas suited to various crops.

Soil erosion is a constraint to crop growth throughout the study area. Areas with high potential for erosion are shown in the soil resource inventory. Perennial forages which can be used for energy crop production may provide an alternative erosion controlling crop to be grown in rotation with food crops. Perennial forages also have the potential to help maintain the soil resource base by adding organic matter, and legumes may add nitrogen to the soil.

The results show large areas as being dominantly unsuited to crop production due to rock fragments which limit use of some types of equipment. Low pH and high water tables are also common soil characteristics found which can limit the areas where crops are grown or limit the type of crops grown. The frigid temperature regimes of the northern regions represent a large area with climatic restraints to traditional crop production. The many soils in the study area which are moderately deep or have fragipans or are underlain by dense basal till may restrict rooting depth and cause a reduction in yields. Small areas of land occur with problems of low available water-holding capacity or flooding hazard. Low available water-holding capacity and flooding hazard are not dominant production problems at the scale of this planning project; however, they may be important restraints to production in localized areas.

The study can be used to predict soil related problems likely to occur in an area, to identify areas most suitable for production of biomass to be used for conversion to energy, and to provide soil data for use in crop simulation models. The study demonstrates how an automated

soil data storage, retrieval and display system can facilitate land use planning on large areas of land.

Through the efforts of the National Cooperative Soil Survey the soil data base is constantly being updated and enlarged. With a computerized soil data bank and map preparation techniques, it will be possible to easily update, expand or focus the soil inventory to correspond to the new knowledge in the area of soils and crop growth.

For further details on the soil resource inventory, see Hanford (1987).

II. FIELD AND LABORATORY EXPERIMENTS

FIELD RESEARCH PROCEDURE

This research was conducted at 9 sites throughout New York State. The region has a temperate, humid climate. The average length of the freeze-free season (temperatures >0°C) is 130-150 days. Average total precipitation during the freeze-free season is 40-46 cm. Average annual rainfall is 95 cm. Accumulated growing degree days (base 10°C) range from 2,000-2,400 in the locations used in this study. Figure 1 shows the sites chosen for this study and the soil types at each site.

Site and Species Selection

Sites chosen for this study fall into five general categories, four of which have major soil limitations indicated by the soil resource inventory to be of importance in the geographical area of study. The soils used and species determined by the soil resource inventory to be adapted to those soils were the following:

1. Soils on acid glacial till with a udic moisture regime which are typically acidic, low in bases and fertility, and have restricted rooting depth. Grasses, grass-legume mixtures, and forage brassicas are potentially suited to these environments. For this study, a Mardin channery silt loam (coarse-loamy, mixed, mesic Typic Fragiochrept) was chosen.

2. Soils on acid tills with an aquic moisture regime which have all the limitations of the first category, but, in addition, are chronically wet. Reed canarygrass is potentially suited to this soil type. In this series of experiments, an Erie channery silt loam classified as a coarse-loamy, mixed, mesic Aeric Fragiaqualf was used.

3. Soils on lacustrine sediment with a udic moisture regime which are fine-textured and have medium base and nutrient supplies. The fine soil texture results in tillage problems and restricts seedling emergence. Grasses, grass-legume mixtures, and forage brassicas are most well-suited to these environments. A Collamer silt loam (fine, silty, mixed, mesic Glossoboric Hapludalf) and a Collamer-eroded silt loam (fine, silty, mixed, mesic Glossoboric Hapludalf) were selected for this study.

4. Soils on lacustrine sediments with aquic moisture regimes which are chronically wet, in addition to the limitations of the lacustrine sediment-udic regime soils. Reed canarygrass is potentially suited to these environments. Two soils which typify this type and were used in this study are the Madalin sandy clay loam (fine, illitic, mesic Mollic Ochraqualf) and the Rhinebeck sandy clay loam (fine, illitic, mesic Aeric Ochraqualf).

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Key:

	Location	Soil Type
1	Willsboro	Madalin
2	Willsboro	Rhinebeck
3	Geneva	Honeoye-e
4	Hector Nat'l. Forest	Erie
5	Aurora	Kendaia
6	Ithaca	Collamer
7	Ithaca	Collamer-e
8	Ithaca	Erie
9	Freeville	Mardin

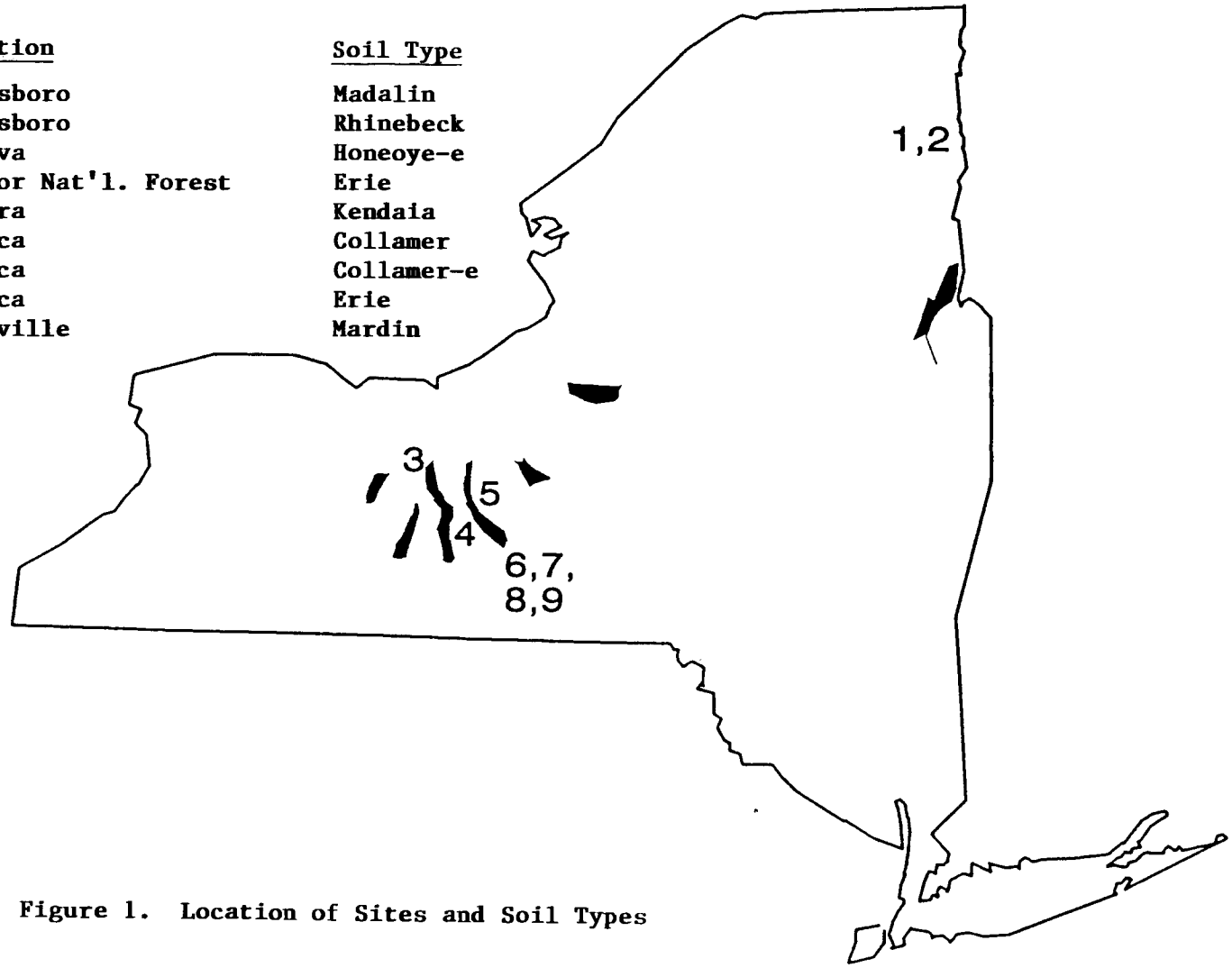

Figure 1. Location of Sites and Soil Types

5. Two soils with minimal limitations were included. These were soils with a calcareous glacial till parent material. A Honeoye-eroded silt loam (fine-loamy, mixed, mesic Glossoboric Hapludalf) and a Kendaia silt loam (fine-loamy, mixed, nonacid, mesic Aeric Haplaquept) were used in this study.

Table 1 shows the soils used, their limitations to crop growth, and species which were established on each soil.

Experimental Design

At each of the 9 sites four randomized complete blocks were created. The main plots in a block were species, the first subplot was fertility treatment and the final split was harvest management system.

Establishment of Species

Soil testing was performed at the initiation of the experiment. Five cores were taken from each plot and composited. This composite sample was then analyzed to determine the nutrient status of the soil. The detailed results of the soil testing procedure are available from the authors. The condensed results of this prestudy soil testing are shown in Table 2. (Soil testing was repeated at the conclusion of the study and is discussed in a later section.)

Fertility Treatments. Based on the soil tests, a fertility program was developed for biomass production. The basic fertility treatments are given in Table 3. Specific fertilizer treatments given as N-P_2O_5-K_2O added annually are shown in Appendix A.

Fertilizer treatments in the establishment year were for establishment purposes only. Thereafter, the fertilizer treatments were intended for maintenance of optimum yield. In 1985 an attempt was made to establish fertility treatments of 1) no added fertility, 2) half the recommended rate, and 3) the recommended rate of fertilization. However, those plots with no added fertility grew extremely poor on Madalin and Rhinebeck soils, especially in subsequent years. The following basic fertility treatments were used: 1) minimum level of input (one-half of the normal recommendation for optimum production), 2) normal recommendation for optimum production, and, 3) twice the normal recommendation for optimum production of the species under consideration.

Sufficient fertility information was available for most species, but, where information was lacking, reasonable estimates were made based on experience with similar species. In all cases, the fertility was added when it was most advantageous to the species in question. Forage brassica was fertilized in early April. Alfalfa-bromegrass, flatpea, kale, meadow, reed canarygrass, and timothy-redtop-red clover plots were fertilized in late April. Fertilizer was applied to sudangrass annually at planting in early June, and switchgrass and eastern gamagrass were fertilized in late June. These treatments were delayed until these species were actively

Table 1. Soil Resources and Species

Plant Species	Series	Soil Resource Limitations
Alfalfa-bromegrass (Medicago sativa, Bromus inermis)	Collamer, Collamer-e	periodic wetness, erosion
	Honeoye-e	erosion
Eastern gamagrass (Tripsacum dactyloides L.)	Erie	acid soil, infertility, fragipan
Flatpea (Lathyrus sylvestris L.)	Mardin	acid soil, infertility, fragipan
	Collamer, Collamer-e	periodic wetness, erosion
Forage brassica (Brassica napus)	Honeoye-e	erosion
	Kendaia	none
Kale (Brassica oleracea)	Mardin	acid soil, infertility, fragipan
Meadow (mixed species)	Erie	acid soil, infertility, periodic wetness
	Madalin	chronic wetness
	Rhinebeck	chronic wetness
Reed canarygrass (Phalaris arundinacea L.)	Erie	acid soil, infertility, fragipan
	Madalin	chronic wetness
	Rhinebeck	chronic wetness
Sudangrass (Sorghum sudanensis)	Honeoye-e	erosion
	Kendaia	wetness
	Mardin	acid soil, infertility, fragipan
Switchgrass (Panicum pratense)	Collamer, Collamer-e	periodic wetness
	Honeoye-e	erosion
	Mardin	acid soil, infertility fragipan

Table 1. Soil Resources and Species (cont.)

Plant Species	Series	Soil Resource Limitations
Timothy-redtop-red clover (*Phleum pratense*, *Agrostis gigantea* L., *Trifolium pratense*)	Collamer, Collamer-e	periodic wetness
	Erie	acid soil, infertility, fragipan
	Kendaia	none
	Honeoye-e	erosion
	Madalin	chronic wetness
	Mardin	acid soil, infertility, fragipan
	Rhinebeck	chronic wetness

Table 2. Soil Test Values at Initiation of Experiment

Soil	Depth (cm)	pH	Soil Test Values P	K	Mg	Ca
			(mg kg soil^{-1})			
Collamer	0-15	6.8	6.5	40	50	1647
	15-30	6.9	4.8	35	42	1551
Collamer-e	0-15	6.6	6.0	42	78	1685
	15-30	6.4	4.3	42	91	1268
Erie	0-15	6.7	5.8	38	187	2538
	15-30	6.8	4.2	31	191	2418
Erie (meadow)	0-15	6.2	1.5	83	102	1763
	15-30	5.8	0.5	41	63	928
Kendaia	0-15	7.6	2.3	33	300	3794
	15-30	7.6	1.2	25	310	3909
Honeoye-e	0-15	7.2	7.7	82	283	1635
	15-30	7.2	5.0	53	262	1625
Madalin	0-15	7.0	0.6	61	535	3712
	15-30	7.2	0.5	47	520	3042
Mardin	0-15	5.6	1.8	60	24	937
	15-30	5.6	2.0	65	25	909
Rhinebeck	0-15	6.9	2.0	41	280	2138
	15-30	7.1	1.0	34	342	2111

Table 3. Basic Fertility Treatments

Species	Fertility Level	N-P-K*
Alfalfa-bromegrass	1	0-½-½
	2	0-1-1
	3	0-2-2
Eastern gamagrass	1	½-½-½
	2	1-1-1
	3	2-1-1
Flatpea	1	0-½-½
	2	0-1-1
	3	0-2-2
Forage brassica		1-1-1
Kale		1-1-1
Meadow	1	0-½-½
	2	0-1-1
	3	1-2-2
Reed canarygrass	1	½-½-½
	2	1-1-1
	3	2-1-1
Sudangrass	1	½-½-½
	2	1-1-1
	3	2-1-1
Switchgrass	1	½-½-½
	2	1-1-1
	3	2-1-1
Timothy-redtop-red clover	1	0-½-½
	2	0-1-1
	3	0-2-2

*times recommended rate

growing and the fertility treatment would not benefit the cooler season grasses as it would if applied earlier in the season.

No N was applied to the leguminous species or mixtures (meadow, alfalfa-bromegrass, timothy-redtop-red clover); N was added at the highest level of fertilization on the meadow plots to test the yield response to the increased N, even though the legume fraction was expected to decrease. During 1986 and 1987, a split application of N was used on kale, switchgrass, eastern gamagrass, reed canarygrass, and sudangrass at the highest level of fertility. Also, in 1986, the P and K applications were applied in two treatments at the highest level of fertility to some timothy-redtop-red clover, alfalfa-bromegrass, and flatpea. The grasses (eastern gamagrass, switchgrass, reed canarygrass, sudangrass) response to added N was also investigated by applying N-P-K in the rate of 1/2-1/2-1/2 times recommended rate, 1-1-1 times recommended rate, and 2-1-1 times the recommended rate. Because the forage brassica/sudangrass was a forage brassica variety trial, only one level of fertility, the normal recommended rate, was used. When sudangrass was the second crop in this double crop system, it also had only one level of fertility.

Seeding Techniques. All plots were limed as needed to a pH of 6.0. Alfalfa plots were limed to a pH of 6.5. Sites were plowed and disked before seeding (no tillage or seeding was done on meadow plots which were established in an old stand.) Tillage of annual species was performed with a Troy Bilt roto-tiller. Plots were seeded using a Carter cone seeder with 17 cm row spacing. All species at all sites were seeded between May 2 and June 5 in the year of establishment with the following exceptions: 1) Madalin and Rhinebeck sites were too wet to work before August, so the seedings were not done until then, 2) forage brassica was planted in late August or early September each year, and 3) eastern gamagrass was established from rooted cuttings in June and October. Tables 4 and 5 give the seeding rates and planting dates for each species.

Pest Control. Use of herbicides, insecticides, and mowing (in the year of establishment) were held to a minimum throughout the study. Those treatments which were used to limit competition by noncrop species and prevent damage from insects are given in Appendix C.

Harvest Management. In this study, the species were harvested on the conventional schedule and also on a schedule which lagged behind the conventional by two weeks (hereafter, referred to as the lax harvest management system), so that the optimum harvest management could be determined for biomass production. A Gravely custom sickle bar mower was used to harvest all species except flatpea. The tangled vines characteristic of flatpea required a Carter plot harvester for cutting.

Table 6 indicates the harvest schedule. Alfalfa-bromegrass plots were harvested two times (lax) or three times (conventional method) to determine which was the most advantageous for dry matter production. Likewise, the timothy-redtop-red clover and meadow plots were cut once (lax) or twice (conventional method). Flatpea, kale, sudangrass,

Table 4. Seeding Rates

Species	Variety	Planting Rate ($kg\ ha^{-1}$)
Alfalfa	Oneida VR	13.2
Bromegrass	Saratoga	8.8
Eastern gamagrass	Liberty Hyde Bailey	*
Flatpea	Lathco	38.5
Forage brassica	Emerald	6.6
Forage brassica	Windal	6.6
Forage brassica	Dwarf Essex	6.6
Forage brassica	Ramon	6.6
Forage brassica	Hobson	6.6
Kale	Maris Kestral	6.6
Reed canarygrass	common	11.0
Redtop	common	4.4
Red clover	Arlington	8.8
Sudangrass	Piper	55.0
Switchgrass	Cave-in-Rock	11.0
Timothy	Climax	6.6

*Established from rooted cuttings on a 0.3 m x 0.3 m grid.

Table 5. Planting Dates

Soil	Species	Planting Date
Collamer	All	5-06-86
Collamer-e	All	5-02-86
Erie	Eastern gamagrass	6-04-86 (rep 1)*
		10-10-86 (rep 2)*
	Sudangrass	6-05-86
	Others	5-23-85
Erie	Meadow	OLD STAND
Kendaia	Sudangrass	May, annually
	Kale	May, annually
	F. brassica	August, annually
Honeoye-e	Kale	May, annually
	Sudangrass	6-03-87
	F. brassica	August, annually
	Others	5-30-85
Madalin	Kale	May, annually
	Meadow	OLD STAND
	Others	8-13-85
Mardin	Kale	May, annually
	Others	5-22-85
Rhinebeck	Kale	May, annually
	Meadow	OLD STAND
	Others	8-12-85

*Eastern gamagrass was established by using rooted plants which were planted on a 0.3 m x 0.3 m diagonal grid.

Table 6. Harvest Schedule

Species	Harvest Mngt System	Harvest Timing (by month)
Alfalfa-bromegrass	C	early 7, mid 7, early 9
	X	mid 6, early 9
Brassicas		early 6
Eastern gamagrass		early 10
Flatpea		mid 8
Meadow	C	mid 6, mid 9
	X	mid 7
Reed canarygrass	C	mid 6, mid 9
	X	mid 7
Sudangrass		late 8
Switchgrass		mid 8
Timothy-redtop-red clover	C	mid 6, mid 9
	X	mid 7

C = conventional harvest management system
X = lax harvest management system Table 5

switchgrass, and forage brassica were only cut once as late in the season as possible.

All species were cut to a height of two cm except switchgrass and eastern gamagrass, which were cut to a height of 15 cm to protect the growing points. (In the first year, a cutting height of five cm was also tested on the switchgrass, but this caused a high mortality rate and was abandoned. A higher stubble height was also tested for flatpea, but no advantage was noted, so a two cm stubble height was used in subsequent years.)

In 1985 all plots, except the kale, were mown in early August. The kale was harvested on November 5. Environmental conditions were limiting in some years, and it was not possible to harvest the species as scheduled because of limited regrowth. Therefore, some harvests were not made.

The actual harvest dates are given in detail in Appendix C.

LABORATORY ANALYSES PROCEDURE

Time and budget constraints prevented all samples from being analyzed. Table 7 shows which samples were analyzed. The samples were dried in a 70°C oven until they reached a constant weight. They were then ground to pass a 20mm sieve.

Neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent ash (ADAsh) and acid detergent lignin (ADL) were analyzed according to the standard procedure (Goering and Van Soest, 1970). From these values, percent cell contents, percent hemicellulose, percent cellulose were determined. Where cell contents = 1 - NDF; hemicellulose = NDF-ADF; cellulose = ADF -(ADL + ADAsh).

Total nitrogen content (percent) was analyzed using the Kjeldahl method. Percent dry ash was determined by ashing the samples for five hours at 500°C.

FIELD RESEARCH RESULTS

Detailed yield data including botanical information (percent legumes, grasses, and weeds in each plot) were collected. Summarized yield data are presented in this report. The detailed data is available from the authors. Only differences which have been found to be significant using an alpha value of 0.05 in an LSD test are described as "significant" throughout this section. Unless otherwise noted, all figures show only significant differences.

Table 7. Samples on which Chemical Analyses were Performed.

Soil	Species	Year 86	Year 87	Year 88	Cut/System[a]	Fert. Levels
Collamer	Alfalfa-bromegrass					
	*Flatpea		X	X	*	all
	Switchgrass					
	Timothy-redtop-red clover			X	1C, 1X	all
Collamer-e	Alfalfa-bromegrass	X			1X	all
	*Flatpea		X	X	*	all
	Switchgrass		X			all
	Timothy-redtop-red clover		X		2X	all
Erie	*Eastern gamagrass		X		*	all
				X		all
	Meadow		X		1X	all
				X	1C	all
	*Reed canarygrass	X			1C,1X,2C	all
			X		2C	all
				X	2C,2X	all
	Sudangrass	X			1C,1X	all
	Timothy-redtop-red clover		X		1X	
Honeoye-e	Alfalfa-bromegrass					
	*Flatpea	X	X	X	*	all

Table 7. Samples on which Chemical Analyses were Performed (cont.)

Soil	Species	Year 86	Year 87	Year 88	Cut/System[a]	Fert. Levels
Honeoye-e	*Forage brassica		X		5 varieties	all
	*Sudangrass		X		*	all
	Switchgrass					
	Timothy-redtop-red clover			X	1C	all
Kendaia	Kale		X			
	Sudangrass	X				
Madalin	Meadow		X		1X	all
	Reed canarygrass		X		1C,1X	all
	Switchgrass			X	*	all
	Timothy-redtop-red clover	X			1X	all
				X	1C	all
Mardin	*Flatpea	X	X	X	*	all
	Forage brassica					
	Kale	X				
			X			
	Sudangrass			X	*	all
	*Switchgrass	X			*	all
			X		*	all
				X	*	all
	Timothy-redtop-red clover					

Table 7. Samples on which Chemical Analyses were Performed (cont.)

Soil	Species	Year 86	Year 87	Year 88	Cut/System[a]	Fert. Levels
Rhinebeck	*Flatpea		X		*	all
				X	*	all
	*Meadow	X			1C,1X,2C	all
			X		1C,1X,2C	all
				X	1C,1X,2C	all
	Reed canarygrass	X			1X	all
			X		1C	all
				X	1C	all
	Switchgrass			X	*	all
	*Timothy-redtop-red clover	X			1C,1X,2C,2X	all
			X		1C,1X	all
				X	1C,1X	all

[a] 1C in this column is the first cutting of the conventional harvesting system, 2X would indicate the second cut of the lax harvesting system, etc.
'*' in Cut/System column indicates only one cutting was taken and only one harvest management system was used for this species throughout the course of the experiment.

* beside species indicates all samples at this location were analyzed for all years.

Yields by Soil Type

Figure 2 shows the mean (averaged over all treatments for all years) and maximum yield for the soils. The maximum yield is the highest yield obtained over the course of the experiment for any one treatment. The species grown on the well-drained soils (Collamer, Collamer-e, Honeoye-e, and Kendaia, Mardin) out-produced those grown on poorly drained soils (Madalin, Rhinebeck, Erie) by an average of about 2,000 kg ha^{-1} over five years. Of the well-drained soils, the Mardin soil was the least productive as might be expected from initial soil test results. This soil is also located in an area with slightly cooler average temperatures than the Collamer and Collamer-e soils. The erodibility of the soil (Collamer-e, Honeoye-e) did not seem to significantly limit these soils production potential. In fact the Collamer-e soil tended to do as well as or better than the Collamer.

Of the poorly drained soils the Erie soil yielded the highest overall. The Madalin and Rhinebeck and Erie meadow soils were all very low in exchangeable P which likely contributed to the relatively poor yields. In 1988, when the rainfall was below normal, the mean yields on these soils were only 500 kg ha^{-1} less than on the well-drained soils.

Yields by Species

Unless otherwise indicated, the yields presented in this section do not include the establishment year. Table 8 shows all yields by site, species, harvest system and fertility. A detailed discussion of that data follows.

Alfalfa-bromegrass. Yields of alfalfa-bromegrass on the better soils have been extremely good (Figure 3). After the seeding year yields jumped to approximately 8,000 kg ha^{-1}. Yields continue to increase slightly on the lax plots, but those cut three times a year (conventional system) are beginning to drop off as would be expected with this intensive harvesting. This species is clearly more productive on a biomass basis using the two-cut or lax system. The fertility treatments did not significantly affect the yield of alfalfa-bromegrass at any of the sites. The Honeoye-e soil has provided the highest yields of this species. The yields on Collamer and Collamer-e soils have been very comparable. The Collamer-e soil has produced slightly higher yields overall. Yields of 10,000-12,000 kg ha^{-1} will not be unusual on the well-drained soils with adequate fertility and a lax cutting management system.

The plots averaged 40% alfalfa, 42% bromegrass and 18% weedy species. Second and third cuts consistently had higher percentages of alfalfa (40-80%) than did the first cuts (approx. 40%). The fertility treatments and harvest management system did not significantly affect the percentage of alfalfa in the plots. The percent alfalfa in the plots increased from less than 20% in the first year to an average of 50% in 1988. In 1989 the alfalfa began to drop off and averaged only 31% of the total dry weight of the plots.

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Figure 2. Mean and Maximum Yields by Soil Type

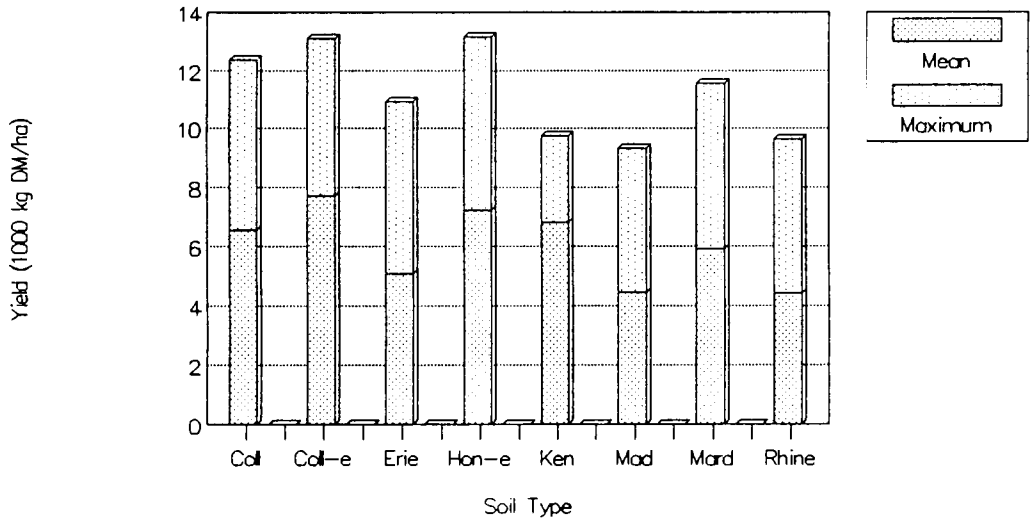

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Figure 3. Alfalfa–bromegrass Yields

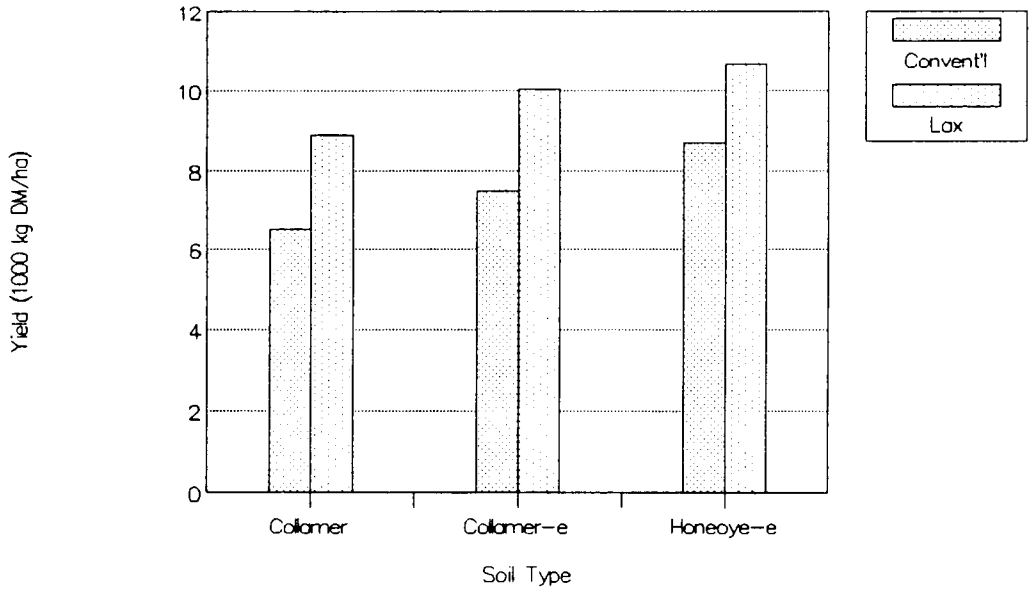

Table 8. Yields by Year, Soil, Species, Harvest Management System and Fertility

Species	Soil	System[a]		Fertility 1	Fertility 2	Fertility 3
Alfalfa-bromegrass	Collamer	C	86	1626	1754	1806
		C	87	6670	7129	8213
		C	88	5949	5770	6572
		C	89	5821	5860	6618
		X	86	2037	2065	1978
		X	87	7258	7373	7945
		X	88	9369	8940	10721
		X	89	9254	9106	9965
	Collamer-e	C	86	2254	2255	2121
		C	87	8004	7995	8843
		C	88	5766	7488	7173
		C	89	7329	7408	7388
		X	86	2361	2102	2350
		X	87	9747	10276	8673
		X	88	10827	10247	9766
		X	89	10312	10582	10001
	Honeoye-e	C	86	8604	8774	8812
		C	87	8965	8704	8694
		C	88	9808	8598	9613
		C	89	8102	7321	8359
		X	86	8408	8774	8812
		X	87	10477	10157	10255
		X	88	11756	12571	11574
		X	89	11784	11639	11956
Eastern gamagrass	Erie		87	5946	7915	8009
			88	6181	6989	7434
			89	3093	4516	4686
Flatpea	Collamer	C	87	6636	8787	8232
		C	88	9215	9199	9361
		C	89	11502	10015	12342
	Collamer-e	C	87	8631	8430	6101
		C	88	7549	6633	6173
		C	89	10853	11594	11929

Table 8. Yields by Year, Soil, Species, Harvest Management System and Fertility (cont.)

Species	Soil	System[a]		Fertility 1	Fertility 2	Fertility 3
Flatpea	Honeoye-e	C	86	4218	4520	3785
		C	87	11354	9668	9552
		C	88	5508	5318	5673
		C	89	13047	12101	13145
		X	86	3416	2639	1840
	Mardin	C	86	4807	5431	5302
		C	87	7477	8479	9147
		C	88	4228	4342	4971
		C	89	9839	9008	9591
		X	86	3454	4418	3923
			89			
Forage brassica	Kendaia	DE[b]		9722		
		EM		9054		
		HO		8345		
		RA		5678		
		WI		8681		
Kale	Kendaia		86	2523	4504	8042
			87	8137	6370	9678
	Madalin		85	276	2196	3073
			86	2196	5056	7721
	Mardin		85	5696	7425	9053
			86	6104	8755	11579
			87	3555	3501	4773
	Rhinebeck		85	369	1407	1971
			86	2390	5860	7312
Meadow	Erie	C	86	3632		
		C	87	2467	2649	3701
		C	88	5937	6374	8589
		C	89	2419	3052	4526
		X	86	1788		
		X	87	3454	3879	4613
		X	88	3747	3848	4754
		X	89	4380	5473	6615

Table 8. Yields by Year, Soil, Species, Harvest Management System and Fertility (cont.)

Species	Soil	System[a]		Fertility 1	2	3
Meadow	Madalin	C	86	3239	4718	5031
		C	87	856	1138	2569
		C	88	5311	5682	6729
		C	89	4981	6766	6522
		X	86	1923	3183	4156
		X	87	2268	3331	4891
		X	88	2910	3506	4425
		X	89	4562	5567	7271
	Rhinebeck	C	86	2643	4543	5586
		C	87	1613	2297	3260
		C	88	3967	4973	5207
		C	89	6473	7167	7285
		X	86	2240	3833	4838
		X	87	2626	3525	4435
		X	88	2680	3296	4298
		X	89	4007	4908	5076
Reed canarygrass	Erie	C	86	4127	5510	6924
		C	87	4179	4759	6882
		C	88	3744	5158	8094
		C	89	5775	5928	7713
		X	86	3916	4357	4626
		X	87	5111	5884	7735
		X	88	6887	7460	10933
		X	89	4427	4938	8502
	Madalin	C	86	1814	3280	4199
		C	87	1648	3211	3362
		C	88	6259	6866	9319
		C	89	6210	7365	8704
		X	86	2053	3252	3802
		X	87	3477	5974	5907
		X	88	3127	4520	7031
		X	89	5313	7674	8161
	Rhinebeck	C	86	2235	3617	4708
		C	87	3389	3880	3675
		C	88	5226	6800	7472
		C	89	7343	8173	9632

Table 8. Yields by Year, Soil, Species, Harvest Management System and Fertility (cont.)

Species	Soil	System[a]		Fertility 1	2	3
Reed canarygrass	Rhinebeck	X	86	2210	3205	4886
		X	87	3856	5378	6022
		X	88	3235	4083	5948
		X	89	4472	5144	7431
Sudangrass	Erie	C	86	2035	2228	3583
		X	86	2616	3136	5781
	Honeoye-e	C	87	10948		
		C	88	3151		
	Kendaia	C	86	3557	4478	5821
		C	87	8118		
		C	89	3363		
		X	86	6245	7373	9765
	Mardin	C	88	4949		
Switchgrass	Collamer	C	86	1073	1439	2136
		X	86	894	1128	1249
		X	87	6479	6954	7890
		X	88	6148	7727	7700
		X	89	11306	10015	12372
	Collamer-e	X	87	6968	8391	7555
		X	88	6199	6450	7294
		X	89	13107	9629	11183
	Honeoye-e	C	86	2892	2839	3887
		X	86	1165	1431	1932
		X	87	7600	7371	7583
		X	88	3139	3348	2802
		X	89	7271	6508	6456
	Madalin	X	87	2205	2461	3383
		X	88	3370	3754	4519
		X	89	3293	4650	6652

Table 8. Yields by Year, Soil, Species, Harvest Management System and Fertility (cont.)

Species	Soil	System[a]		Fertility 1	Fertility 2	Fertility 3
Switchgrass	Mardin	X	87	3233	4197	4691
		X	88	2465	3519	4132
		X	89	2519	3190	4247
	Rhinebeck	X	87	2311	2571	2490
		X	88	3156	3793	4251
		X	89	3956	5464	5755
Timothy-redtop-red clover	Collamer	C	86	1788	1682	2070
		C	87	7375	7414	7225
		C	88	7521	7649	8012
		C	89	7280	7461	7683
		X	86	2046	1953	1825
		X	87	7684	8474	7093
		X	88	7463	7768	7284
		X	89	9073	9779	8768
	Collamer-e	C	86	2848	2984	3281
		C	87	7915	8678	8613
		C	88	5578	6169	6858
		C	89	9098	9003	9739
		X	86	3373	3703	3318
		X	87	10314	9822	10238
		X	88	7523	9161	8547
		X	89	12458	12036	11154
	Erie	C	86	5589	6535	6641
		C	87	2551	3458	3469
		C	88	4051	4002	3763
		C	89	4414	4597	4615
		X	86	6835	8067	7809
		X	87	3998	4619	4417
		X	88	4147	4225	4259
		X	89	4507	4449	4507
	Honeoye-e	C	86	7715	7239	7315
		C	87	6467	6812	7357
		C	88	5703	5741	6158
		C	89	4542	3973	5802

Table 8. Yields by Year, Soil, Species, Harvest Management System and Fertility (cont.)

Species	Soil	System[a]		Fertility 1	2	3
Timothy-redtop-red clover	Honeoye-e	X	86	6568	7102	7590
		X	87	6883	5976	6214
		X	88	4808	4781	5027
		X	89	10433	9533	9683
	Madalin	C	86	2239	3207	4044
		C	87	1395	2297	3822
		C	88	3717	4612	4981
		C	89	5130	8062	8085
		X	86	2523	4795	5723
		X	87	2903	3941	4957
		X	88	3007	2968	4188
		X	89	7743	7168	8360
	Mardin	C	86	6545	6352	7205
		C	87	5518	5764	6138
		C	88	6552	6573	6971
		C	89	4162	5229	6253
		X	86	8390	7314	7538
		X	87	5625	6107	6542
		X	88	7733	8058	8156
		X	89	4706	6275	6972
	Rhinebeck	C	86	2639	5475	6233
		C	87	1718	3649	4103
		C	88	2409	3362	3949
		C	89	6638	5939	7439
		X	86	3440	6504	7022
		X	87	3759	4668	5340
		X	88	2112	2979	3344
		X	89	5319	5485	5870

[a]C=conventional harvest management system
X=lax harvest management system

[b]Variety:
DE=Dwarf Essex RA=Ramon
EM=Emerald WI=Windal
HO=Hobson

Eastern gamagrass. Eastern gamagrass is still in preliminary study, but the yields have not been extremely impressive. Because of the limited number of replications of this species, response to fertility is not statistically significant, but clearly the trend is for yields to increase with higher levels of fertility (Figure 4). This species has responded very well to the first increment of fertility, but additional N (fertility level 3) did not increase yields further. This species is another which is capable of yields of over 8,000 kg ha^{-1} with adequate fertility.

Limited plant resources have prevented testing of this species on a wider range of soil limitations. If this species is to become a serious contender for biomass production on a large scale establishment practices must be simplified. Hand setting rooted plants is simply not viable for a crop grown for its biomass production.

Flatpea. Flatpea is a species which holds promise for biomass production. Establishment did not present any major difficulties and yields of this species have increased substantially every year, except in 1988 when extreme dry weather inhibited the growth of the flatpea, allowed cool season grasses to become established, and thereby reduced yields up to 50% (Figure 5). The flatpea has been very aggressive in filling in the plots. In 1989 the composition of the flatpea plots averaged 98% flatpea after beginning in 1986 with only around 70% flatpea. Flatpea virtually died out on the Rhinebeck soil where soil drainage is poor. Growth on the Mardin soil has consistently been less than that on the better Collamer, Collamer-e and Honeoye-e soils, but yields over 9,000 kg ha^{-1} have been reached even at this poorer site.

Increasing fertility inputs has not significantly improved yield of this species; yield of plots with the lowest level of fertilizer has equalled those with the highest input on the average. Fertility had no appreciable effect on weed control.

One harvest of this crop approaches the yield of alfalfa-bromegrass. Harvesting requires equipment other than that traditionally used for haymaking because of the vines produced by this species.

Kale. Kale was tested at several sites and the yields were among the highest of any species evaluated. Kale did respond to increased fertility both from added boron and N, P, and K (Figure 6). Doubling the N applied from level 2 to level 3 fertility had a very obvious and significant impact on biomass production. It is likely that further refinement of fertility practices would continue to increase yield. This species thrived on the better drained soils.

However, these yields were reached only with intensive management and aggressive pest control throughout the growing season (see Appendix B.) This is a major drawback to its production for use as a biomass species and for that reason it was removed from our studies after 1987. While its yields were very good, the added time and materials required for such yields far outweigh the benefits of the increased biomass yields.

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Figure 4. Eastern gamagrass Yields by Fertility Level

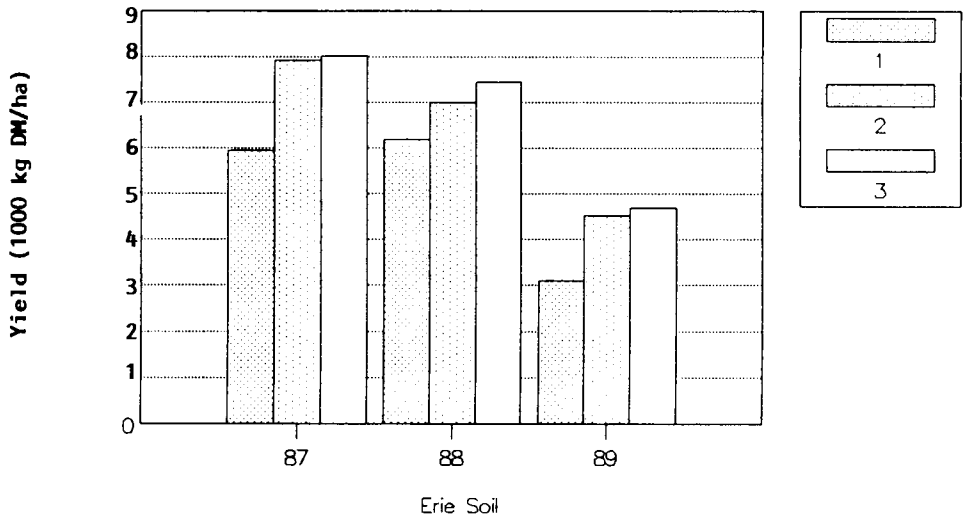

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Figure 5. Flatpea Yields

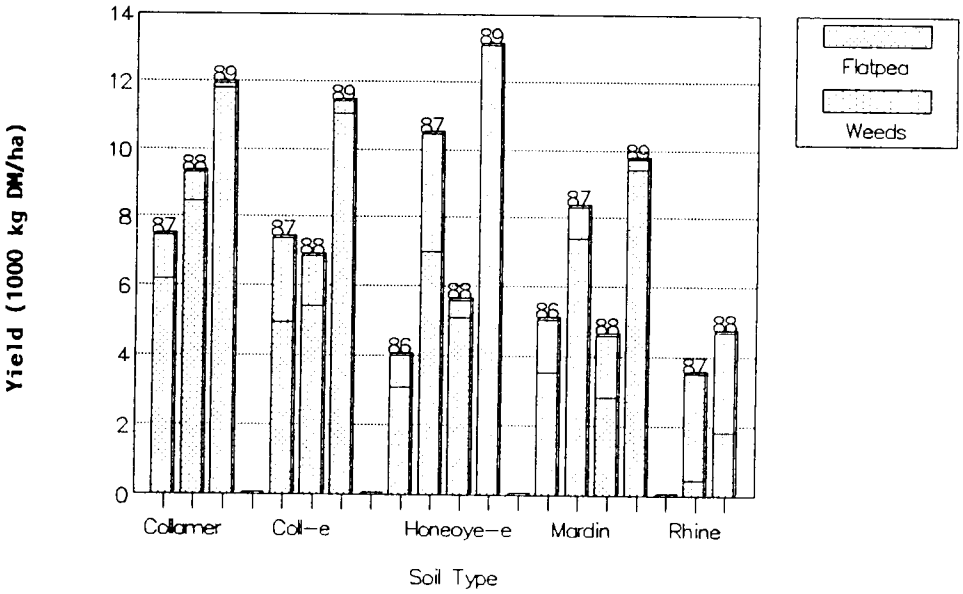

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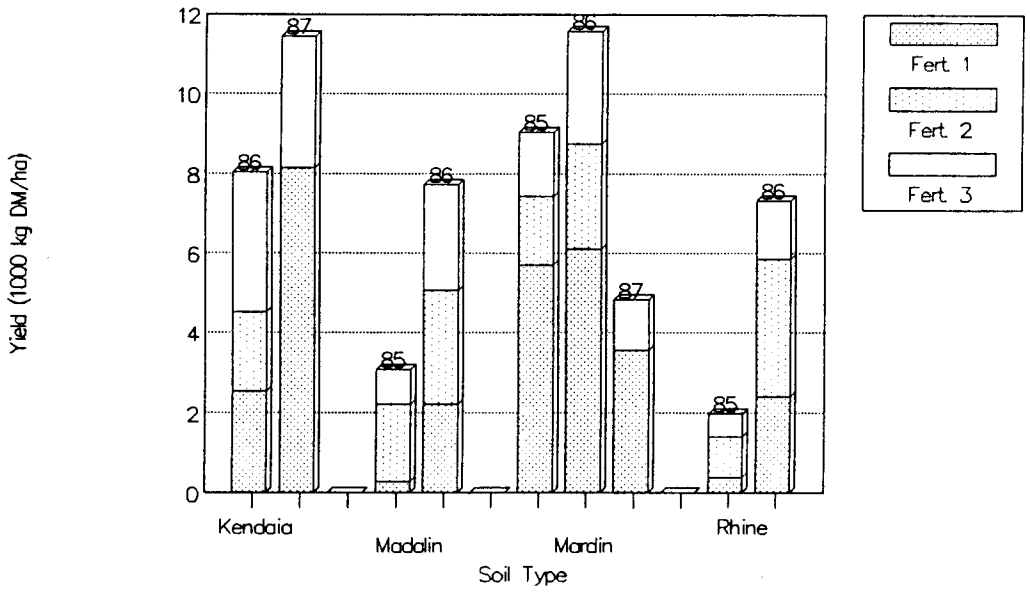
Figure 6. Kale Yields



Meadow. The meadow plots were the subject of much interest during this study. No inputs were used to establish them and the only input used at all was fertilizer. The plots were located on wet soils where tillage is generally not possible until mid- to late summer. The meadow harvests are also a reasonable choice for shallow or stony land where cultivation would cause erosion or is difficult due to rock fragments.

Yields of 5,000 kg ha^{-1} have been attained several times (Figure 7). The Erie soil has produced as much as 8,500 kg ha^{-1} . On the Erie soil, the meadow stand did not respond significantly to P and K fertilization, but did utilize added N (level 3). The naturalized meadow sites on Madalin soils have shown a positive response to all added fertility. Meadow stands on the Rhinebeck soil responded to N (level 3 fertility), but did not show a consistent response to P and K, but, on the average, additional P and K did increase biomass yields.

Second cuttings of the plots favored the leguminous species. Harvest management system did not affect the composition of the plots. Increasing the fertility from the lowest to the second level increased the percentage of legumes in the plots. The addition of N to the highest level of fertility favored nonleguminous species but the loss of legumes from these plots was more than offset by the increased productivity of the other species.

The best cutting management system has not been clearly determined. In 1986 and 1988 where two harvests of the conventional plots were possible, the conventional system was best. In 1987 limited regrowth made only one conventional harvest possible and the lax cutting was most productive. No consistent increases or decreases in yield have been seen over the four years that these plots were under study.

Reed canarygrass. Reed canarygrass has shown good potential as a biomass species for use on poorly drained soils. Dry matter yields have steadily increased since the beginning of the experiment (average yields: 1986-3,818 kg ha^{-1}; 1987-4,685 kg ha^{-1}; 1988-6,231 kg ha^{-1}; 1989-6, 828 kg ha^{-1}) and weeds have not become established in these plots. Increased N fertilization did improve yields at all sites (Figure 8). In fact on soils where high levels of additional N was not provided, N deficiency symptoms were present. It is probable that some of the added N was lost to denitrification on these poorly drained soils. The necessity of high levels of P and K was not clearly demonstrated in this study as few significant responses to these nutrients were found; one-half of the recommended rate of P and K in most cases produced as much biomass as the full rate.

Yields up to 10,000 kg ha^{-1} have been possible on well-fertilized Erie soil. Yields of over 7,000 kg ha^{-1} are not uncommon on soils when an adequate level of N is present.

The response to cutting management has been similar to that of the meadow sites. Where two cuts of the conventionally managed plots have been possible, the conventional system has outyielded the lax. In 1987

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Figure 7. Meadow Yields by Fertility Level

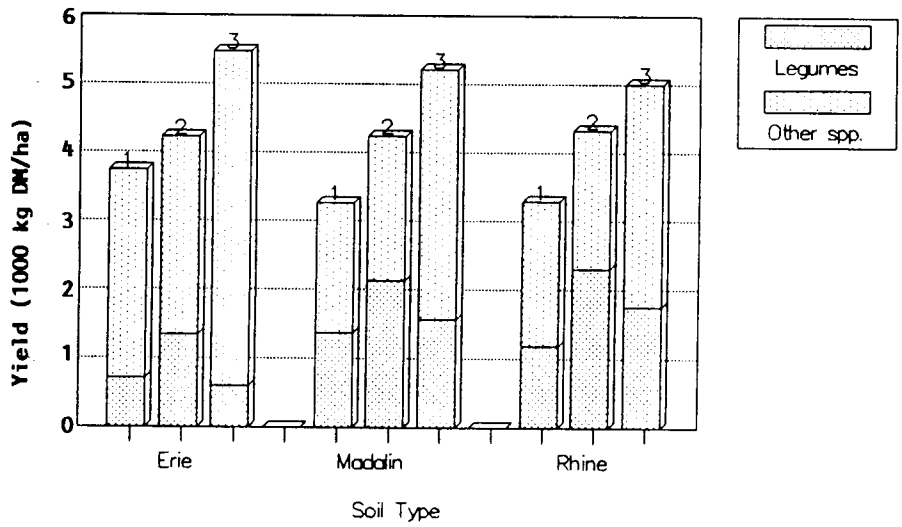

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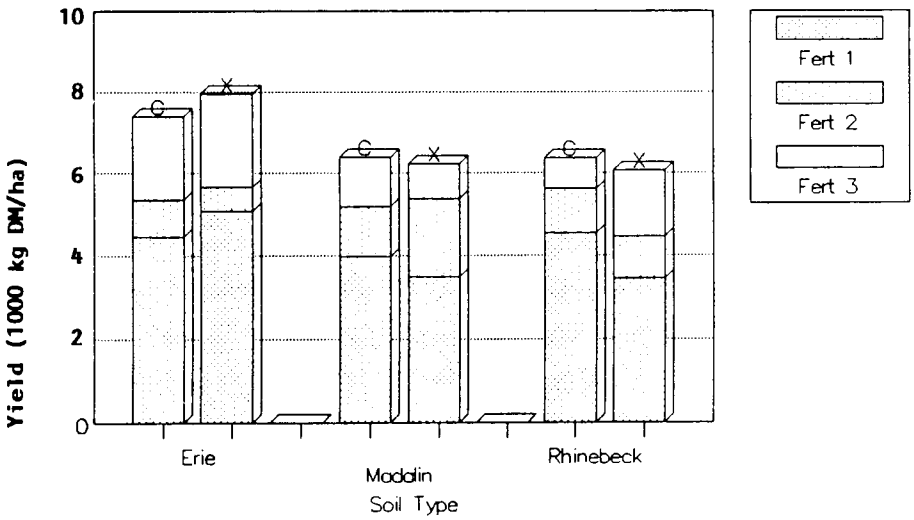
Figure 8. Reed canarygrass Yields by Harvest Management System



the lax cuttings yielded much better than the conventional due largely to the absence of a second conventional harvest.

This species provides a large amount of biomass with only one harvest. The timing of the harvests (mid-July) also coincides with favorable weather conditions. The wetter soils on which reed canarygrass grows have usually dried out by this time and the harvesting equipment can get into the field.

Sudangrass/forage brassica. Sudangrass and the forage brassica double cropping system was been tested at four sites with mixed results. About one-third of our attempts to establish one of these species failed because of lack of precipitation causing poor germination and/or herbicide damage or a heavy rainfall after planting washing seeds out of the ground. Average yields from the Honeoye-e and Kendaia soils are shown in Figure 9. The other sites did not produce as well and in many cases at least one of the species failed each year. These species can provide over 15,000 kg ha^{-1} annually in this double cropping system. The dry weather in 1988 greatly reduced the yield of sudangrass, but can produce 10,000 kg ha^{-1} with moderate fertility given normal weather conditions.

Forage brassica yields on the Honeoye-e soil averaged around 4,700 kg ha^{-1}. Yields of up to 10,000 kg ha^{-1} of forage brassica make a double crop system the highest yielding of any combination tested.

Forage brassica will not survive on poorly drained soils so this rotation is restricted to sites without serious drainage problems. In addition the slope of the site should be negligible as the annual tillage required for this system would cause excessive erosion on steeply sloped land. The need to establish two crops a year is a tremendous drawback.

Switchgrass. After the establishment year switchgrass yields remained fairly constant at each site over the duration of the experiment, although the Collamer and Collamer-e sites did show a large (30%) increase in yield from 1988 to 1989. Switchgrass did not respond significantly to added fertility on the well-drained Honeoye-e, Collamer, and Collamer-e soils although there was a trend for increased yields with increased fertility (Figure 10). The more poorly drained sites did show a significant increase in dry matter yield with increased fertility. Yields of 7,000 kg ha^{-1} were obtained on relatively good soils such as the Collamer and Honeoye-e, but this figure dropped to around 4,000 kg ha^{-1} on the poorer soils.

A stubble height of 15 cm was necessary to ensure survival of the stand. Switchgrass is slow to establish and effective weed control is essential, especially for cool season grasses (see Appendix B.) The weedy species which were mainly the cool season grasses averaged 1.5% of the biomass at the Collamer and Collamer-e sites, rose to over 20% on the Honeoye-e, Madalin and Rhinebeck soils and composed more than 50% of the biomass on the Mardin site over the course of the experiment. This species shows some promise for production of biomass but may not be the preferred one when compared to other higher yielding species which are

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Figure 9. Sudangrass and Forage brassica Yields

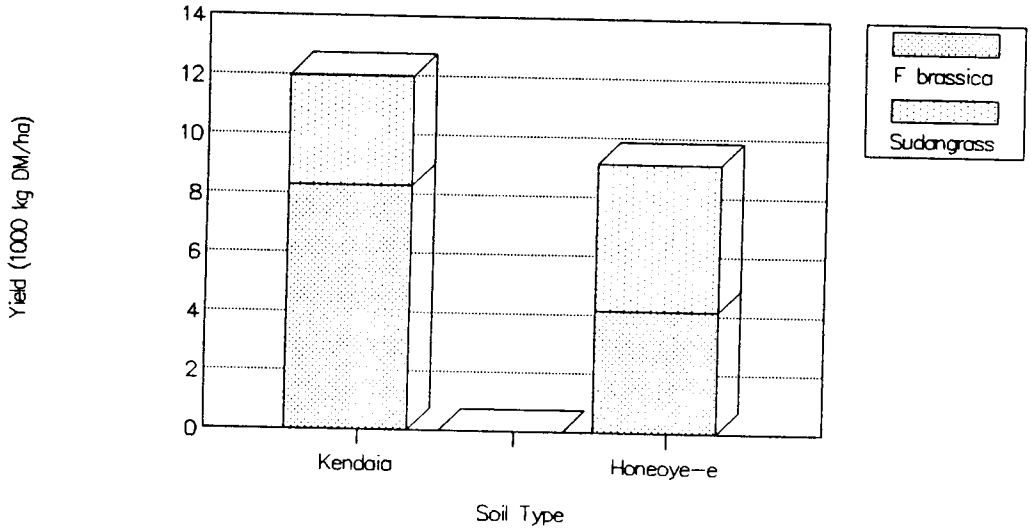

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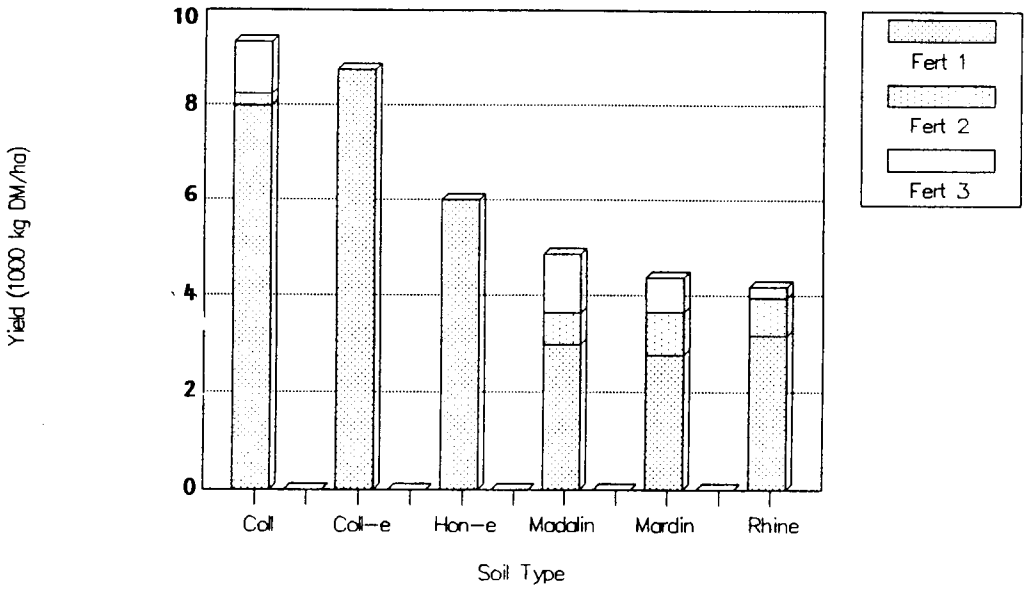
Figure 10. Switchgrass Yields



more easily maintained. Another possible source of problems is the variety which was chosen for this study. The Cave-in-Rock (var.) used in these trials may not be the best-suited for the growing conditions. Another variety better adapted to the conditions in central New York State may have less problems with weeds establishing and yield should increase, providing a more favorable outlook for this species as a biomass producer.

Timothy-redtop-red clover. This species combination has only been competitive on the well- and moderately well-drained sites. On the better soils yields of up to 10,000 kg ha^{-1} have been attained (Figure 11). Yields of 8,000 kg ha^{-1} are not uncommon on these soils. For this mixture the lax cutting system is the more productive. Fertility response has only been significant on the poorest soils. The maximum yield has most likely not been reached on these less fertile soils. This combination shows most promise on well-drained soils which have adequate fertility.

The botanical composition of these plots varied drastically in the course of the experiment. Site and years after establishment were the most important factors in determining the percentage of red clover (legume) in the plots. As shown in Figure 12, red clover essentially died out of the plots after peaking in its second year. As in the alfalfa-bromegrass plots, the percentage of legume was highest in the second cuttings. Fertility did not significantly affect percentage of red clover except on the Madalin and Rhinebeck soils where the higher fertility treatments did have a higher percentage of legumes in the second year after establishment. Harvest management system did not affect the percentage of red clover in the plots. On the Collamer, Collamer-e, Madalin and Mardin soils the timothy and redtop yields are increasing and biomass production has remained relatively constant or slightly increased following the loss of the red clover.

LABORATORY ANALYSIS RESULTS

All results are reported as "significant" if the means in an LSD test were different with an alpha value of 0.05.

Fiber Analysis

Strong similarities in composition are found in species with similar growth habits. Figures 13 through 16 are generalized charts of fiber analysis by growth habit for those species used in this study. A discussion of the results of the fiber analysis by species follows. Extensive data from the fiber analysis testing is available from the authors.

Alfalfa-bromegrass. NDF, ADF and ADL were influenced most by the percentage of legume in the plots. NDF had a Pearson correlation coefficient of 0.26 with percent legume, ADF 0.56 and ADL 0.73, indicating that as the percentage of legume in the plots increased, so did the amount

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Figure 11. Timothy–redtop–red clover Yields by Harvest Mgmt. System

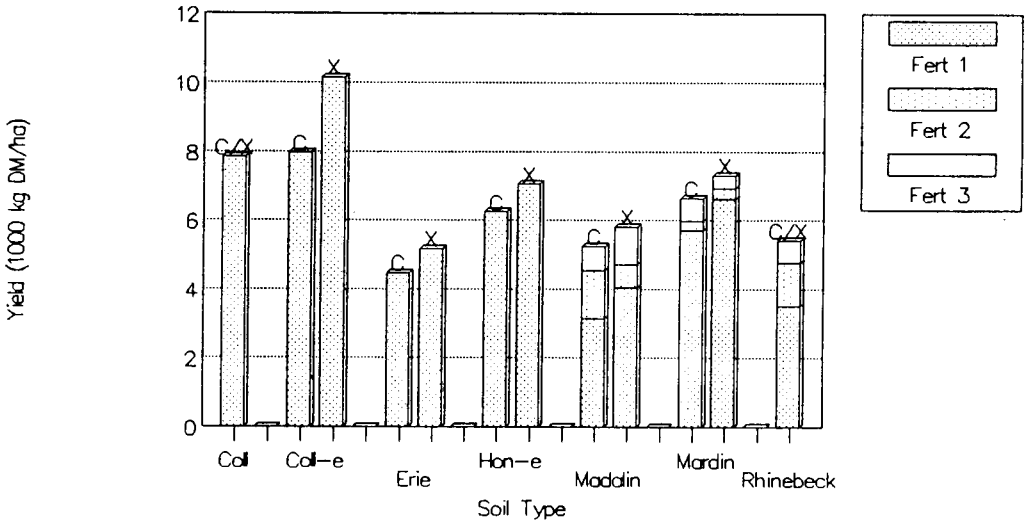

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Figure 12. Percentage Red clover in Timothy–redtop–red clover Plots

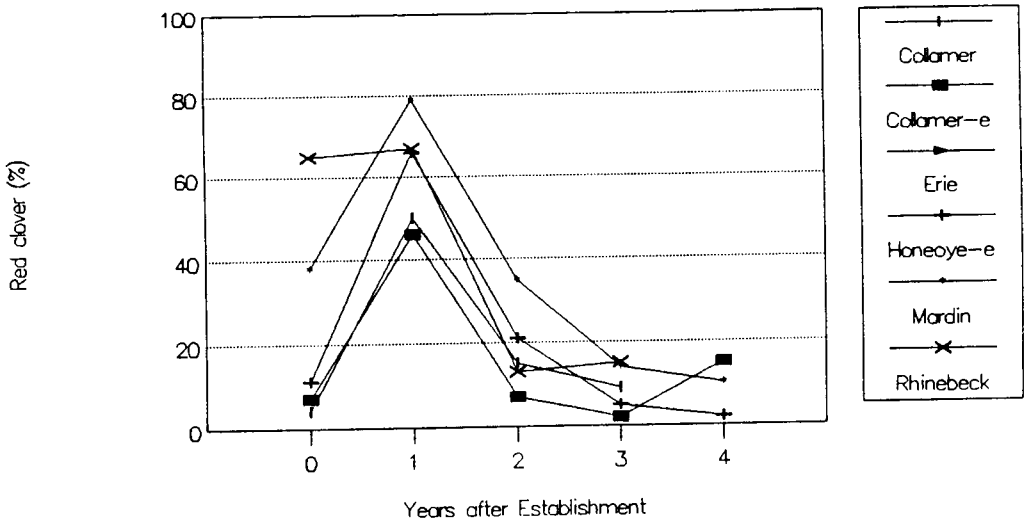

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Figure 13. Chemical Composition of Cool Season Grasses

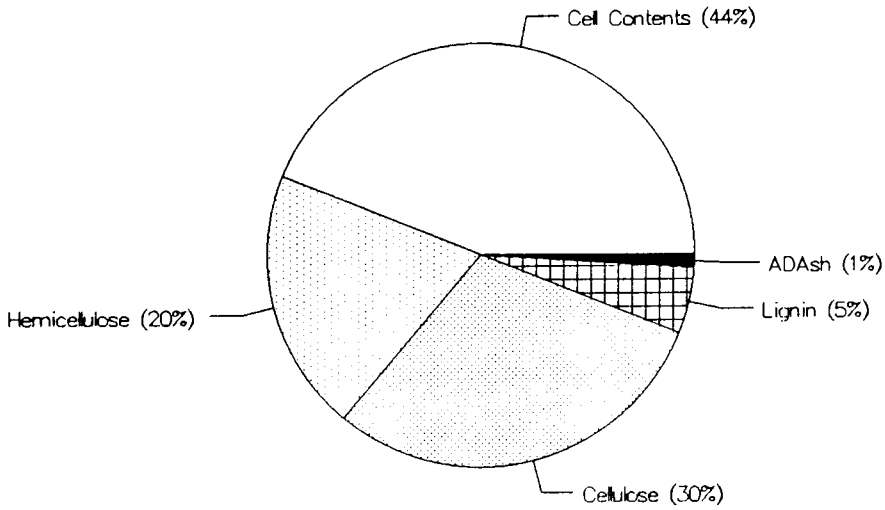

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Figure 14. Chemical Composition of Warm Season Grasses

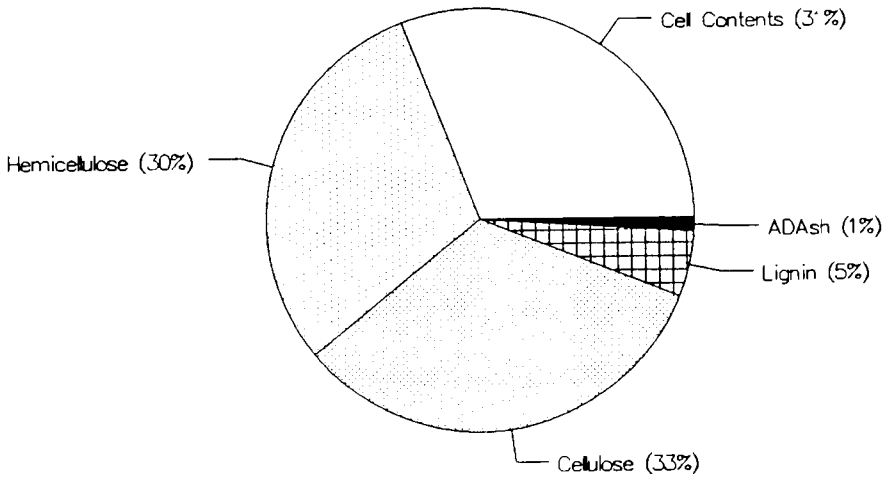

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Figure 15. Chemical Composition of Legumes and Legume Mixtures

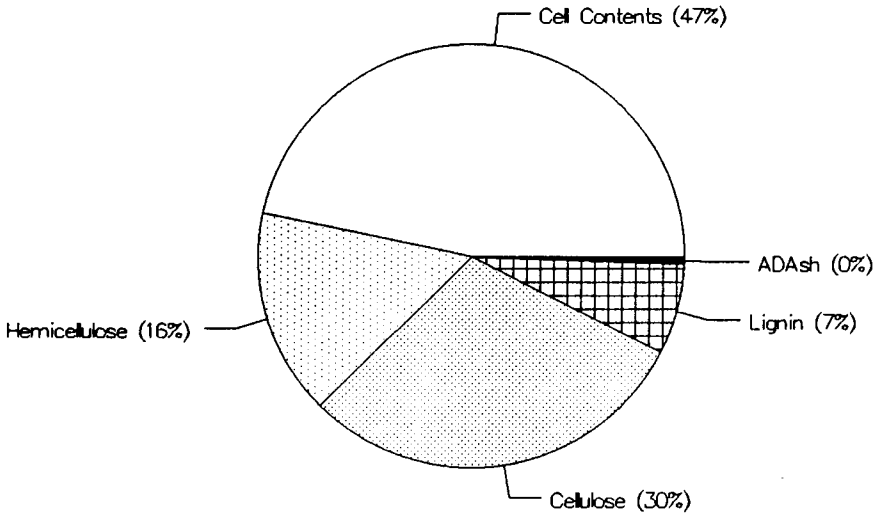

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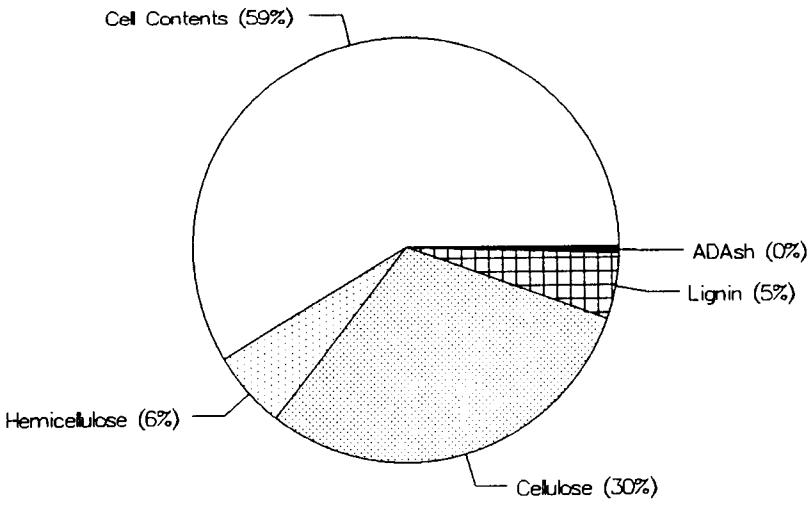
Figure 16. Chemical Composition of Brassicas



of fiber. Fertility and harvest management system did not influence any of those three components. ADL increased slightly, but significantly in the second versus the first cutting. Almost 50% of this species was composed of hemicellulose and cellulose, about 6% was lignin and cell contents account for 47% of the composition of the biomass (Figure 17).

Eastern gamagrass. Eastern gamagrass was grown in one location where the only variable was fertility treatment. The plots were essentially weed-free. Fertility treatment had no effect on fiber content of the eastern gamagrass. This species contained 71% of its mass as hemicellulose and cellulose, and 22% as cell contents which includes sugars which may also be converted to energy (Figure 18).

Flatpea. The treatment factors for flatpea were year, site and fertility. The amount and types of fiber were influenced by one main factor - percentage of weeds (which were mainly grasses) in the plots which was related to the site and time since establishment. (Further explanation given in Field Research Results section. See Figure 5.) NDF and weed percentage had a Pearson product-moment correlation of 0.33 as the percentage of weeds increased (actual NDF fraction increased from 0.50 to 0.57 as percentage of weeds increased from 0 to 98%). ADF and percent weeds had a correlation of 0.34 (ADF fraction changed from 0.39 to 0.43). Lignin was not affected by percentage of weeds (correlation = 0.01).

Only 43% of this legume's biomass was in the form of hemicellulose and cellulose, 48% was in the form of cell contents including soluble sugars (Figure 19).

Forage brassica. Forage brassica is another species which was not subjected to fertility or harvest system treatments. The species was virtually weed-free.

Forty-three percent of this species was composed of hemicellulose and cellulose, and over half (52%) was cell contents (Figure 20).

Kale. No treatments were used on this species. Overall, kale had a very high quantity of cell contents and was very low in fiber content (Figure 21).

Meadow. As discussed in the yield section, increasing fertility increased the percentage of nonleguminous species. As the percentage of nonleguminous species increased only a slight correlation with NDF, ADF and ADL was noted. The Pearson product-moment correlations were as follows: NDF and percent nonleguminous species = -0.16, ADF and percent nonleguminous species = 0.16, ADL and percent nonleguminous species = 0.27. The degree to which the fiber content was changed by the composition of the plot was less than 2% for any component. System had no effect on NDF, ADF, or ADL within a fertility level.

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Figure 17. Chemical Composition of Alfalfa–bromegrass

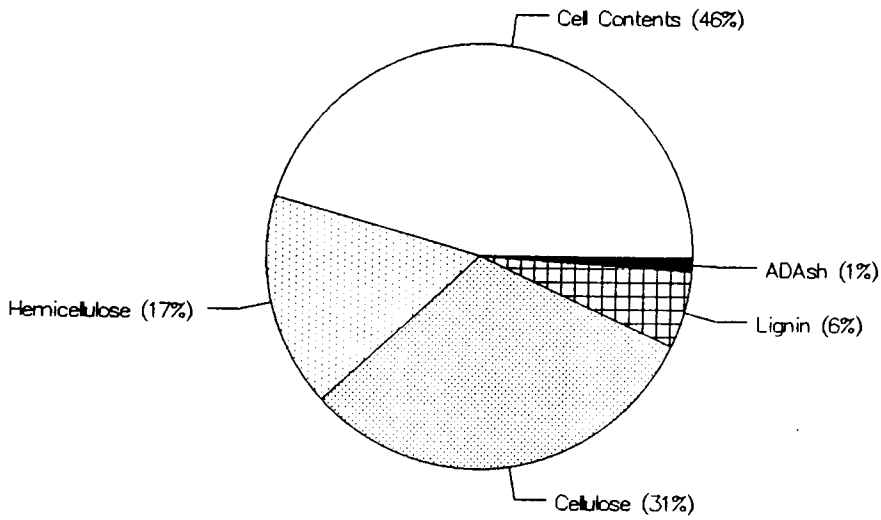

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Figure 18. Chemical Composition of Eastern gamagrass

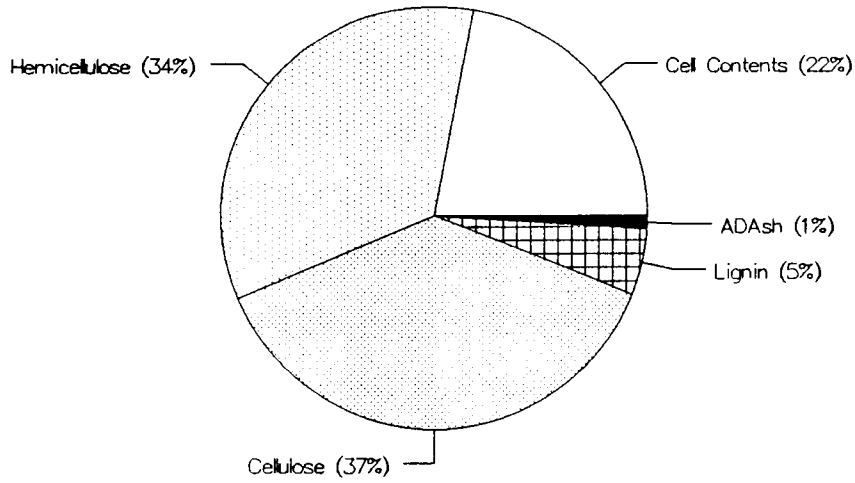

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Figure 19. Chemical Composition of Flatpea

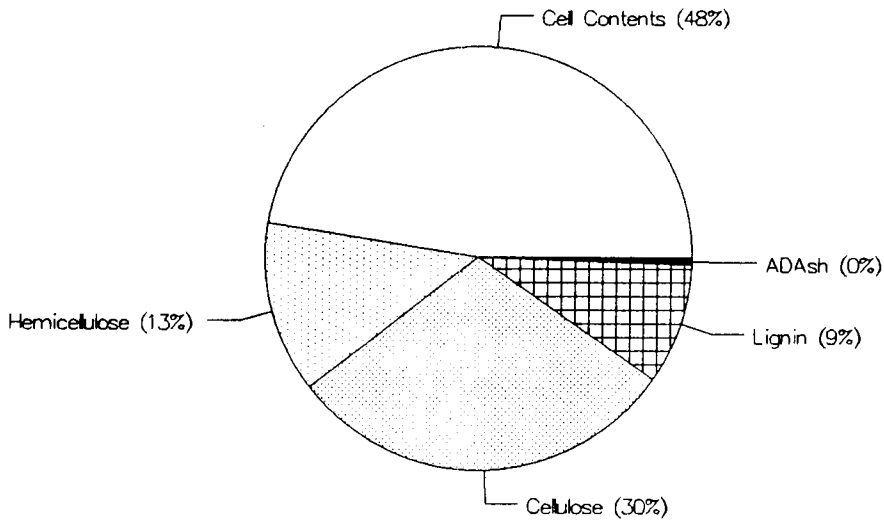

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Figure 20. Chemical Composition of Forage brassica

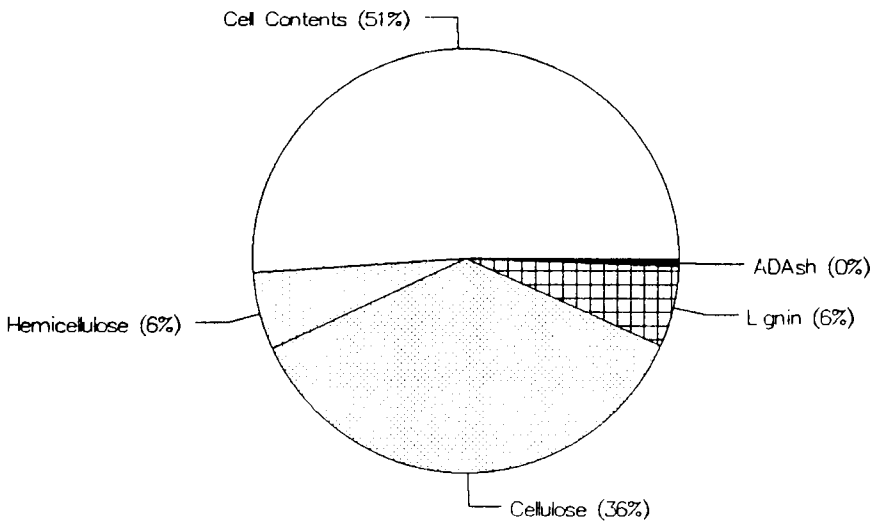

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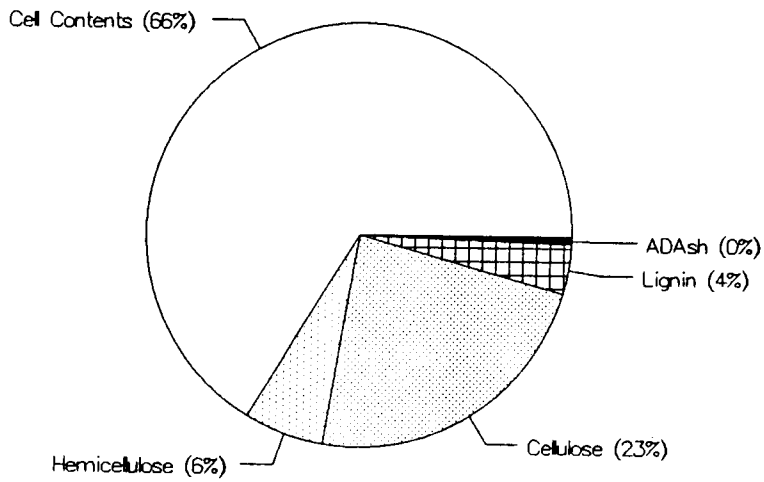
Figure 21. Chemical Composition of Kale



Hemicellulose and cellulose composed 48% of this mixture of species while 46% of the biomass was composed of cell contents and soluble sugars (Figure 22).

Reed canarygrass. This species was essentially weed-free so botanical composition of the plots was not a factor in analyzing fiber composition. The conventional harvest system produced samples with the highest NDF (conventional=0.57, lax=0.55). ADF was only affected by harvest system, again the conventional system produced reed canarygrass with a higher ADF fraction (0.35 vs. 0.34). Fertility did not affect NDF or ADF. Lignin was not influenced by either system or fertility.

Cell contents accounted for 43% of the biomass from this species and the hemicellulose and cellulose fractions made up 52% (Figure 23).

Sudangrass. Sudangrass was another species which was almost a pure stand. Only one level of fertility and one harvest management system was used. The hemicellulose and cellulose fractions of this species accounted for 58% of its biomass and cell contents were 36% (Figure 24).

Switchgrass. Although the actual changes in percent composition of fiber components were less than 3%, fertility was a significant factor on these changes. The second fertility level had a higher percentage of NDF, ADF and ADL than the lowest fertility, but was not significantly different from fertility level 3 where the only nutrient increased from level 2 was nitrogen. Fertility level 3 was equal to fertility level 1 in its fiber content.

Overall, cell contents constituted 36% of this species and hemicellulose and cellulose accounted for another 58% (Figure 25).

Timothy-redtop-red clover. All of the timothy-redtop-red clover which was analyzed was from the Rhinebeck site. Increasing fertility tended to increase NDF and ADL; ADF was significantly increased in the second and third levels of fertility. Lax harvest management system increased ADF, NDF tended to be higher, and ADL was unchanged. Second cuttings produced less NDF, more ADL, and ADF was unchanged. Percent legume in the plots and NDF had a Pearson product correlation of -0.27, ADL and percent legume had a coefficient of 0.32, ADF was not related to percent legumes (coefficient=0.03). Again, the maximum changes were less than 2% of any component.

Cell contents constituted 45% of this species, hemicellulose and cellulose made up 48% and lignin was approximately 7% of the total biomass (Figure 26).

Total Nitrogen

Total nitrogen content varies widely among the species tested (Figure 27). (Refer to Table 7 for a list of samples which were analyzed. Detailed results from the total nitrogen tests are available from the

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Figure 22. Chemical Composition of Meadow

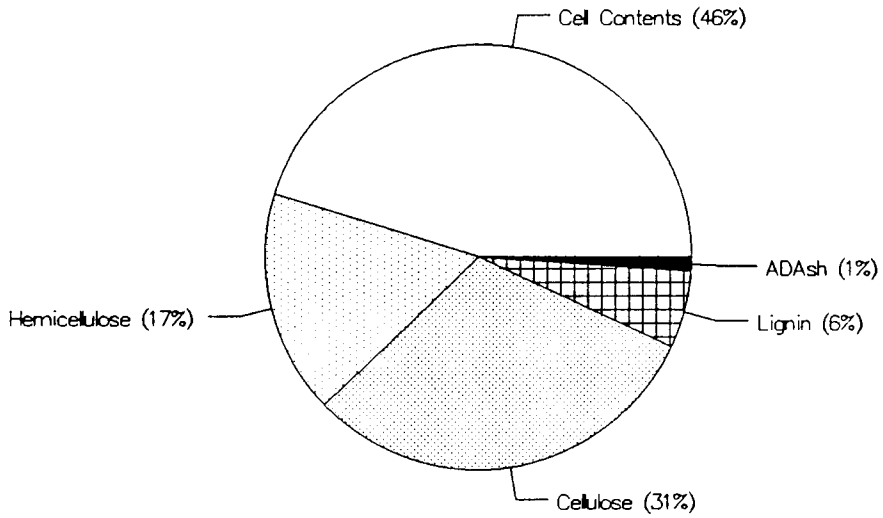

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Figure 23. Chemical Composition of Reed canarygrass

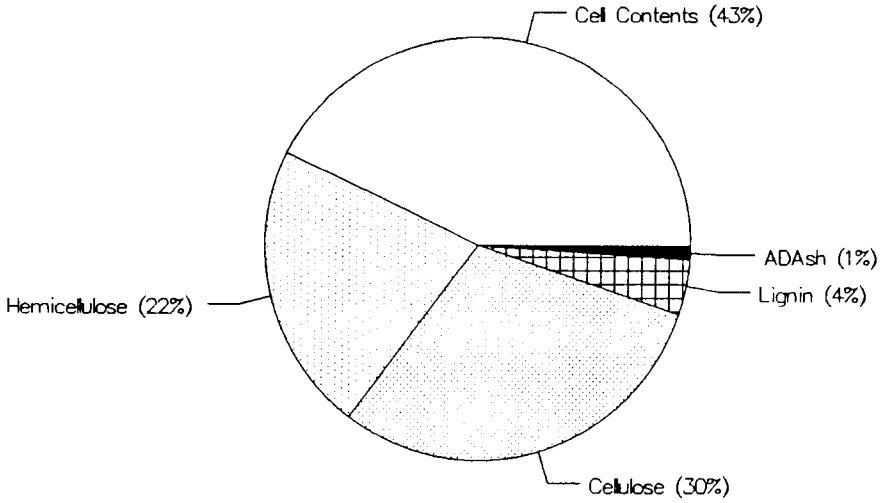

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Figure 24. Chemical Composition of Sudangrass

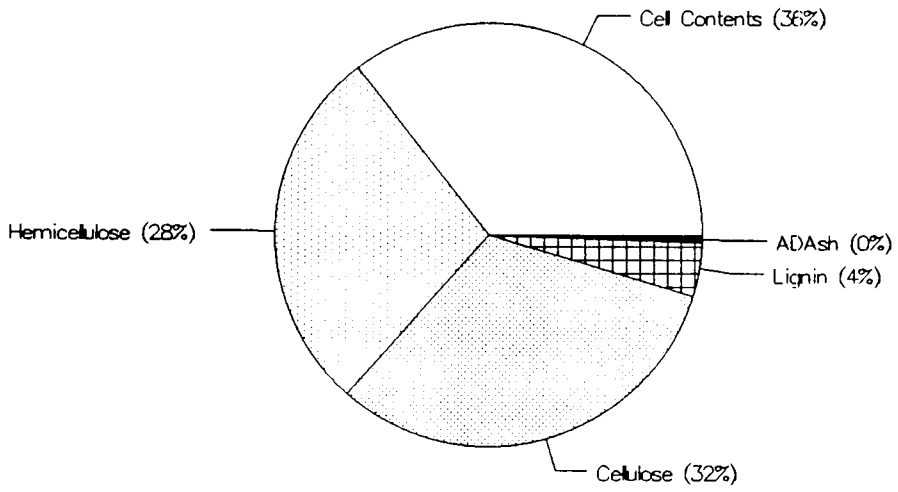

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Figure 25. Chemical Composition of Switchgrass

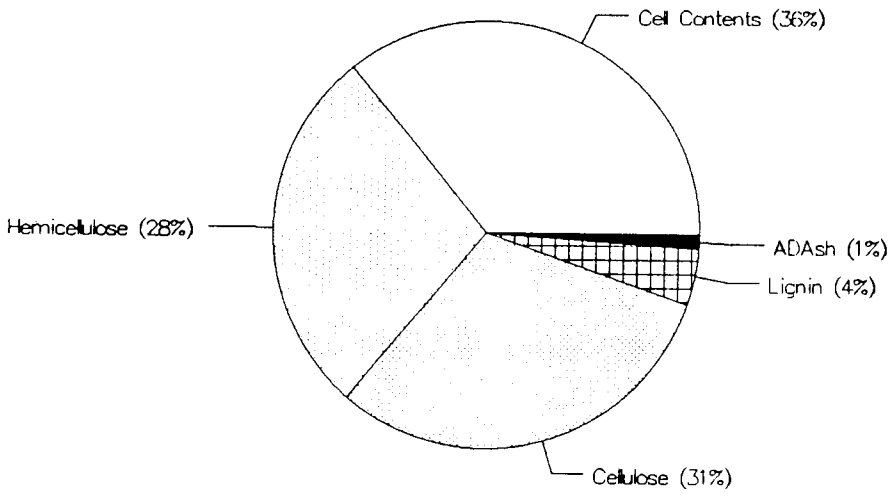

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Figure 26. Chemical Composition of Timothy–redtop–red clover

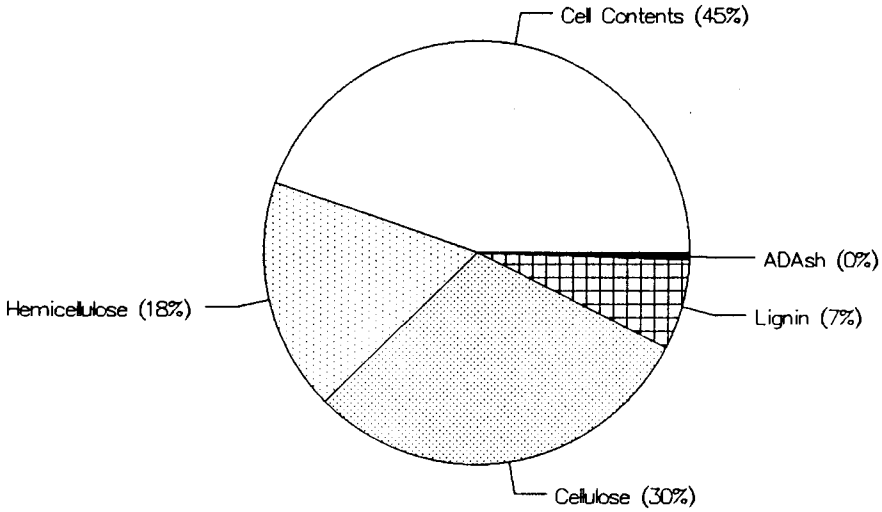

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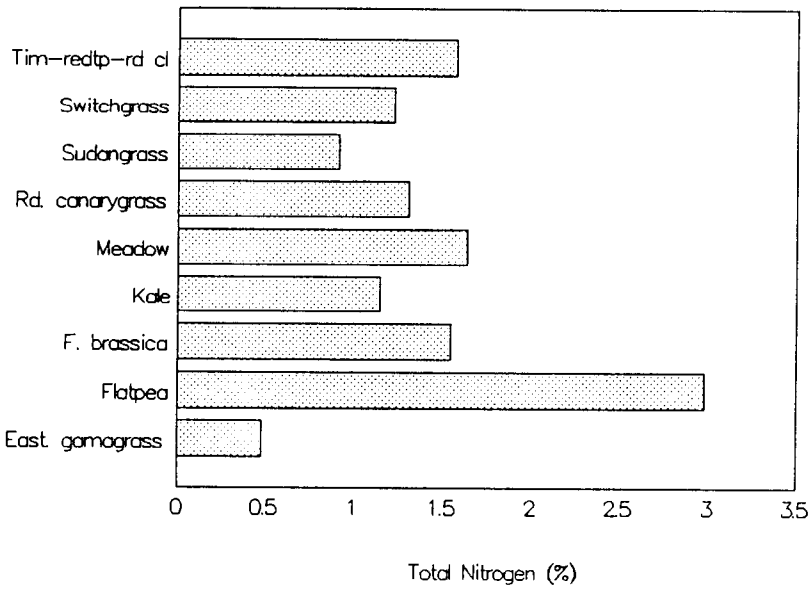
Figure 27. Total Nitrogen Content



authors.) Of all the treatment factors, the harvest management system affected total N most consistently (Table 9). The lax harvest management system had a lower total N than the conventional management system in all of the species tested. Fertility was also a significant factor affecting total N in several instances (Table 10). As expected, total N decreased in legume mixes when fertility increased and caused a loss of legumes. The total N in grasses (except reed canarygrass) tended to increase with fertility. Cut was a significant factor in only a few cases (Table 11). In all instances the second cuttings had higher total N than first cuttings, again corresponding with the legume population in leguminous plots. The emphasis placed on controlling the total N will be determined by the degree to which N, or protein, impedes the conversion to energy.

Dry Ash

Dry ash content is simply what percentage of the sample did not burn at 500°C for five hours. This may be an important factor if the biomass is to be directly combusted.

No correlation of percent legume or percent grass was found to exist with percent dry ash. Increased fertility did decrease ash content in eastern gamagrass (4.7 to 4.1), meadow (7.6 to 6.8), and reed canarygrass (8.3 to 7.4). The lax management system produced a higher percentage of ash in meadow (7.2 to 7.7), switchgrass (5.9 to 7.0) and timothy-redtop-red clover (6.3 to 6.6). Varieties of forage brassica varied significantly in the percent of dry ash (Dwarf Essex 9.0%, Emerald 8.1%, Ramon 8.5%, Hobson 8.0%, Windal 8.2%). (Detailed dry ashing results are available from the authors.)

SOIL TESTING RESULTS

Soil tests (Greweling and Peech, 1965) were made at the initiation of the experiment in 1985 and at the conclusion in the fall of 1989. (Detailed results are available from the authors.) The changes in soil fertility status at a depth of 0-15 cm are shown in Appendix D. At most locations any significant changes in fertility were a loss of nutrients. The fertilizer additions did not keep pace with the quantity of certain nutrients used by the biomass produced. Magnesium was not included in the fertilizer amendments and a significant loss of this nutrient did occur on the Collamer soil. Pretesting indicated already low Mg values on this soil, so this should be a concern for future studies of this type. Significant net losses of P and K were seen at many locations over a range of species.

Two sites which did not follow this trend were the poorer Mardin and Rhinebeck soils. These sites showed slight increases in P and K fertility. The Mardin site was heavily limed at the initiation of the experiment causing the rise in pH and a concomitant increase in available Ca.

Table 9. Effect of Harvest Management System on Total Nitrogen Content

Soil Type	Species	Year	Signif[a]	Total N (%) Harvest Mngt.[b] C	X
Collamer	Timothy-redtop-red clover	88	**	1.01	0.85
Erie	Reed canarygrass	87	***	1.52	0.84
		88	**	1.24	1.13
	Sudangrass	86	***	1.25	0.78
Rhinebeck	Meadow	86	***	1.96	1.34
		87	***	2.05	1.62
		88	***	1.78	1.44
	Timothy-redtop-red clover	86	**	2.09	2.13
		87	***	2.36	2.17

[a] Significance is designated as follows:

If the Pr>F	≤ .001 significance =	***
	≤ .01	**
	≤ .1	*

[b] C=conventional harvest management
X=lax harvest management

Table 10. Effect of Fertility on Total Nitrogen Content

Soil Type	Species	Year	Signif[a]	Total N (%) Fertility Level 1	2	3
Collamer	Flatpea	87		3.81	3.79	3.80
		88		3.04	3.16	2.75
	Switchgrass	87		1.09	1.03	1.04
	Timothy-redtop-red clover	88		0.93	0.91	0.94
Collamer-e	Flatpea	87		3.28	3.67	3.30
		88		2.85	2.37	2.88
	Timothy-redtop-red clover	87		2.14	2.17	2.19
Erie	Eastern gamagrass	87		0.48	0.48	0.47
		88	*	0.49	0.55	0.68
	Meadow	87		1.55	1.41	1.49
		88		1.18	1.24	1.17
	Reed canarygrass	86		1.36	1.49	1.26
		87		1.26	1.32	1.30
		88		1.20	1.16	1.18
	Sudangrass	86		1.08	0.98	0.98
	Timothy-redtop-red clover	87		0.90	0.86	0.71
Honeoye-e	Flatpea	86		3.02	3.11	3.48
		87		3.14	3.03	3.12
		88		1.77	1.77	2.17
	F. brassica	88		-	1.54	-
	Sudangrass	87		-	0.60	-
		88		-	0.82	-
	Switchgrass	86		1.31	1.24	1.54
Honeoye-e	Timothy-redtop-red clover	88		0.84	0.94	0.84

Table 10. Effect of Fertility on Total Nitrogen Content (cont.)

Soil Type	Species	Year	Signif[a]	Total N (%) Fertility Level 1	2	3
Kendaia	Kale	86		1.13	1.06	1.17
		87		1.42	1.79	1.59
	Sudangrass	86	*	0.88	0.80	0.92
		87		-	0.53	-
Madalin	Meadow	87		1.71	1.82	1.42
		88	***	1.52	1.46	1.13
	Switchgrass	88		1.29	1.30	1.40
	Timothy-redtop-red clover	88	*	1.32	1.07	1.00
Mardin	Flatpea	86		3.41	3.86	3.48
		87		3.22	3.52	3.26
		88		3.17	3.16	3.04
	Kale	86		1.07	1.17	1.26
	Sudangrass	88		-	1.32	-
	Switchgrass	87	*	0.92	1.07	1.04
		88	**	1.15	1.22	1.54
Rhinebeck	Flatpea	87	**	1.88	1.98	2.45
		88		-	2.01	2.13
	Meadow	86		1.78	1.78	1.69
		87	**	2.00	1.96	1.54
		88	*	1.73	1.76	1.52
	Reed canarygrass	86	*	1.30	1.04	0.87
		87	*	1.96	1.95	1.64
	Switchgrass	88	*	1.17	1.29	1.41
Rhinebeck	Timothy-redtop-red clover	86		2.02	2.27	2.29
		87		2.21	2.31	2.28
		88	*	1.21	1.11	1.00

[a] Significance is designated as follows:

If the Pr>F	≤ .001 significance =	***
	≤ .01	**
	≤ .1	*

Table 11. Effect of Cut on Total Nitrogen Content

Soil Type	Species	Year	Signif[a]	Total N (%) Cut 1	Total N (%) Cut 2
Erie	Reed canarygrass	86		1.38	1.36
		87		1.19	1.50
		88	***	0.92	1.45
Rhinebeck	Meadow	86	*	1.66	1.93
		87			
		88	***	1.41	2.19
	Timothy-redtop-red clover	86	**	1.95	2.27

[a] Significance is designated as follows:

If the Pr>F	≤ .001 significance =	***
	≤ .01	**
	≤ .1	*

Soil tests were also run on cores taken from 0-5 cm at selected sites at the conclusion of the experiment (Table 12). Few significant differences in nutrient status were seen between fertility treatments, although in many instances the trend is for P and K to increase where higher fertility inputs were used. Because the fertilizer treatments were applied only four or five times and were surface applications, the lack of significant changes should not be unexpected. Even in the 5 cm cores the diluting effect of the soil on the fertilizer would mask any changes which may have been occurring at the surface.

RECOMMENDED SPECIES FOR BIOMASS PRODUCTION

A summary of the species characteristics including yield and laboratory analyses are given in Table 13 and are used as the basis for this section.

Well-drained/moderately well-drained soils

Soils such as the Collamer, Collamer-e, Honeoye-e, and Mardin used in this study have few limitations due to drainage problems. Alfalfa-bromegrass, timothy-redtop-red clover, and flatpea were the highest yielding species on this type of soil. Of these three, flatpea has the important constraint of requiring special harvesting equipment. Timothy-redtop-red clover and alfalfa-bromegrass mixtures yield approximately the same (10,000 kg ha^{-1}) and both produce the most biomass under a delayed or lax harvest management system. The fiber composition of these species is not significantly different; both contain approximately 50% hemicellulose and cellulose, and 45% cell contents. Timothy-redtop-red clover did have a relatively high percentage of nitrogen and ash, but it is not known how important this will be in a conversion process. Of the species tested on soils without drainage limitations, alfalfa-bromegrass and timothy-redtop-red clover are most promising for production of biomass for energy.

Somewhat poorly/poorly drained soils

One species outyielded all others on the Erie, Madalin, and Rhinebeck soils. Reed canarygrass under a one cut system produced almost 7,000 kg ha^{-1}. No pest control was necessary to maintain these yields. Its high hemicellulose and cellulose content (52% total) makes it a promising species for conversion to energy.

The meadow plots also have potential for wet soils. They require no establishment and the only inputs were fertility treatments. With high fertility these plots yielded over 5,300 kg ha^{-1}. The fiber content (hemicellulose and cellulose) of the meadow plots is nearly 50%. This type of unimproved meadow system may also have potential for use as an energy crop.

Table 12. Soil Nutrient Status (0-5 cm depth) 1989

Soil	Fert. Species	Level	pH	Nutrient[a] P	K	Mg	Ca
				(mg kg soil^{-1})			
Collamer	Alfalfa-bromegrass	1	6.69	4.8b	45b	54	1391
		2	6.56	5.9ab	56ab	48	1323
		3	6.69	7.8a	70a	49	1353
	Flatpea	1	6.53	4.6	58b	54	1371
		2	6.47	6.1	72ab	58	1393
		3	6.34	7.3	86	51	1339
	Switchgrass	1	6.65a	6.7	57	45	1385a
		2	6.51b	5.9	45	42	1312ab
		3	6.27c	6.7	71	44	1258b
	Timothy-redtop-red clover	1	6.70	6.3	63a	51	1448
		2	6.63	5.6	46b	48	1406
		3	6.66	4.9	43	48	1404
Madalin	Meadow	1	6.92	1.2b	75	511	3810
		2	6.75	1.7a	76	465	3655
		3	6.94	2.0a	78	500	3652
	Reed canarygrass	1	6.89	0.6b	60	504	3672
		2	6.78	1.3a	57	465	3618
		3	6.69	1.7a	61	451	3597
	Switchgrass	1	7.06a	0.7b	65	546	3995
		2	7.01ab	1.8a	67	522	4060
		3	6.79b	1.6a	65	497	3909
	Timothy-redtop-red clover	1	7.05	0.7b	61	569	4091
		2	7.05	1.2b	58	536	4021
		3	6.93	6.4a	63	540	3951
Rhinebeck	Flatpea	1	6.89	1.4b	65	278	2252
		2	7.01	6.7ab	65	274	2425
		3	6.93	10.9a	74	273	2485
	Meadow	1	6.77	1.8	59	311	2483
		2	6.67	2.3	61	290	2375
		3	6.67	2.6	57	293	2475
	Reed canarygrass	1	6.90	1.2	54	282	2363
		2	6.95	3.6	54	271	2478
		3	6.77	2.7	50	269	2342

Table 12. Soil Nutrient Status (0-5 cm depth) 1989 (cont.)

Soil	Fert. Species	Level	pH	Nutrient[a] P	K	Mg	Ca
				(mg kg soil^{-1})			
Rhinebeck	Switchgrass	1	6.99	1.8b	59	271	2307
		2	6.92	4.6a	55	258	2106
		3	6.71	2.3b	60	244	2226
	Timothy-	1	7.00	1.8b	45	299	2430
	redtop-	2	6.96	3.0b	51	285	2348
	red clover	3	7.03	12.2a	57	274	2331

a,b indicate values which are significantly different based on an LSD test with an alpha value of 0.05.

Table 13. Summary of Species Characteristics Relating to Biomass Production

Species	Advantages	Limitations	Optimal Mngt System
Alfalfa-bromegrass	◦ high yields ◦ legume	◦ need good drainage	◦ lax mgmt system
Eastern gamagrass	◦ high yields ◦ well-suited to wet soils ◦ very high fiber (%) ◦ low % nitrogen	◦ difficult to establish	◦ one cut
Flatpea	◦ high yield ◦ legume ◦ low maintenance	◦ need good drainage ◦ req. special harvest eqpt. ◦ relatively low % fiber ◦ high % lignin and nitrogen	◦ one cut
Forage brassica/ Sudangrass	◦ very high yield	◦ not suited to erosive sites ◦ need good drainage ◦ high % ash (brassica) ◦ low % fiber (brassica)	◦ one cut of each
Kale	◦ very high yield	◦ intensive pest control req'd.	◦ one cut
Meadow	◦ very low input ◦ good yields on marginal soils ◦ legumes	◦ need adequate fertility ◦ high % ash	◦ if two cuts possible, yields will be higher w/ conv.mgmt.
Reed canarygrass	◦ high yield ◦ well-suited to wet soils	◦ high % ash ◦ high fertility needed for highest yields	◦ lax mgmt

Table 13. Summary of Species Characteristics Relating to Biomass Production (cont.)

Species	Advantages	Limitations	Optimal Mngt System
Switch-grass	◦ high % fiber	◦ low yields ◦ need effective weed control ◦ need high fertility for best yields ◦ variety choice important	◦ one cut
Timothy-redtop-red clover	◦ good yield ◦ legumes in first 2 years	◦ need adequate drainage ◦ high % ash ◦ rel. high % N ◦ need high fertility for best yields	◦ lax mgmt system

III. Modeling Objective

DATA FOR MODELING

The first goal of data collection has been completed. The most useful data are the yield numbers collected in the screening trials reported as results of our field research. Two other field experiments were also conducted to obtain additional information helpful in developing and refining biomass yield predictors. Those results are reported below as a part of this section.

We had initially anticipated that it would be necessary to carefully model the accumulation of biomass and therefore we intended to measure the growth curves of our biomass crops by sequential harvesting during development, recording both yields and chemical composition. A trial to do this was established in 1986 with alfalfa-bromegrass mixtures at the eroded Caldwell field site, using a fertility program like that of the biomass yield plots with the same species at the same site. Table 14 summarizes those results.

However, it became clear as the project progressed that final biomass yield should be the main goal of a biomass model. By the time biomass production was optimized (i.e., when biomass crops were harvested near or after physiological maturity), chemical composition was fairly stable, so many species differences could be generalized without modeling the time course of changes in plant chemistry. Likewise, the time course of biomass accumulation was observed to be less important than factors that influenced how much biomass could be harvested (i.e., factors such as fertility and stubble height).

Because ongoing experiments with perennial grasses (originally begun in another project) provided an opportunity to examine the effect of cutting height in detail, we have collected a body of very useful information that will help develop models of the reduction in biomass yield as the height of cutting is increased. For species such as switchgrass and eastern gamagrass that must be given a significant stubble in order to survive, this information will help us adjust general models for the yield reduction caused by greater stubble height. Unfortunately, switchgrass and eastern gamagrass plots were not available for field studies of stubble yields, but as the data in Table 15 show, the stubble yields across species is not highly variable. Data in Table 15 include both percentage yield by canopy layer and total aboveground biomass yield. Coarser grasses (orchardgrass, bromegrass, and reed canarygrass have lower stubble yields than finer grasses (tall fescue, timothy, perennial ryegrass). Switchgrass and eastern gamagrass are probably like the coarser grasses. All of the species considered in Table 15 are potential herbaceous biomass species in their own right. The stubble height trial also provides growth curve data like that reported in Table 15 for additional species. Data for one additional year of the stubble height experiment should be available in a thesis to be published later in 1990.

Table 14. Average yields and standard deviations (SD) of yields for alfalfa-bromegrass mixtures harvested during biomass growth in order to estimate the pattern of biomass accumulation. The stand was on an eroded Collamer soil at Caldwell field, Ithaca, NY, and it was established in 1986 and fertilized according to soil test recommendations.

Harvest date	Stage	Age[a] at harvest	Yield	SD of yield
m-d-y		days	kg of DM/ha	kg of DM/ha
		CONVENTIONAL HARVEST SCHEDULE		
5-7-87	first growth	36	2005	270
5-14-87		43	2380	520
5-21-87		50	3575	370
5-28-87		57	4395	435
6-4-87		64	6385	820
7-9-87	second growth	35	1940	115
7-16-87		42	2120	200
8-20-87	third growth	35	1855	240
9-16-87		62	3255	655
		LAX HARVEST SCHEDULE		
5-26-88	first growth	55	2920	315
6-1-88		61	3410	440
6-7-88		67	5005	325
6-15-88		75	5770	845
6-22-88		82	8630	845
8-4-88	second growth	43	3165	350
8-10-88		49	5035	1250
8-17-88		56	6025	605

[a]Days since April 1 or since the last harvest.

Table 15. Percentage yield of stubble segments and total aboveground biomass yield for six perennial grass species widely grown in the Northeast and Lake States. Stands were established in 1986 on an eroded Collamer soil at Caldwell Field, Ithaca, NY. Forty kg of N/ha were applied in July and again in August each year. Data are for the first growth of the 1988 season.

Species	Harvest date	Stubble increment (cm above soil) 0-5	5-10	10-15	15-20	> 20	Total DM yield
	m-d	- - - - - - - - - % - - - - - - - - -					kg/ha
Tall fescue	5-2	17.7	17.2	16.0	14.1	35.0	3266
	6-8	11.1	10.8	10.2	9.7	58.2	4722
	6-20	10.4	9.7	9.1	8.8	62.0	6697
	7-15	10.7	10.0	9.2	9.0	61.1	6524
Timothy	5-23	15.6	15.9	15.0	13.3	40.2	3972
	6-8	10.0	9.4	9.0	8.7	62.9	5276
	6-20	8.0	7.3	6.9	6.8	71.0	6069
	7-15	8.0	7.4	7.0	6.8	70.8	5876
Perennial ryegrass	5-23	17.9	17.1	16.5	15.0	33.7	4116
	6-8	10.9	10.4	10.0	9.7	59.0	5027
	6-20	9.8	8.8	8.2	8.1	65.1	5641
	7-15	12.8	11.7	10.3	10.0	55.2	5012
Orchard-grass	5-23	10.7	10.9	10.8	10.6	57.0	5315
	6-8	7.3	7.1	7.0	6.9	71.7	6159
	6-20	6.0	5.7	5.5	5.5	77.3	6873
	7-15	6.4	5.9	5.6	5.6	76.5	6324
Brome-grass	5-23	9.0	8.8	8.7	8.8	64.7	5392
	6-8	7.5	7.3	7.2	7.0	71.0	6674
	6-20	6.7	6.4	6.6	6.5	73.8	7940
	7-15	6.9	6.6	6.5	6.5	73.5	7690
Reed canary grass	5-23	10.1	10.9	10.8	10.2	58.0	4988
	6-8	7.8	7.8	7.5	7.1	69.0	7023
	6-20	6.3	6.0	5.9	5.7	76.1	7893
	7-15	6.4	6.1	5.9	5.7	75.9	7932

MODELS

The starting point for modeling was the "LEVEL ZERO" alfalfa model (Fick, 1984). That model was reprogrammed in ACSL (Mitchell and Gauthier Associates, Concord, MA 01742) to run with a Microsoft Fortran Compiler in a DOS 3.1 environment. The ACSL version is appended under the program name HERB (Appendix E). The code has been verified and comment statements in the code document changes from the LEVEL ZERO model. A LEVEL ZERO user's manual is also attached to document program elements not changed in the development of HERB.

The program HERB was next modified to simultaneously compute the biomass production of up to ten different biomass crops or crop management systems. The code for that exercise is also appended under the name HERBIE (Appendix F). The plan was to modify the soil production factor (SPF) so as to more fully incorporate the soil survey data used by Hanford in the soil inventory objective of this project. We also intended to add a soil test/soil fertility module for nitrogen and phosphorus based on the works of Wolf, et al. (1989), Wolf, et al. (1987) and Janssen, et al. (1987) and for potassium based on the work of Rao (1988). Unfortunately, the graduate student assigned to do that work was unable to complete the project and we have only recently identified another individual to continue the work. Our plan is to complete the modeling project with other funding as soon as possible (probably the end of 1991).

As the model is now designed, required inputs will be weather, soil survey, soil test data, and management data. Growth parameters for biomass crops will be a part of the model structure, but only alfalfa parameters have been added at present. Outputs will be estimates of biomass yield, including growth curves as a function of time. An example output for a hypothetical crop (using alfalfa growth parameters) is presented in Figure 28. The cutting management simulated is the optimal two-cut system for maximizing biomass with alfalfa-based mixtures.

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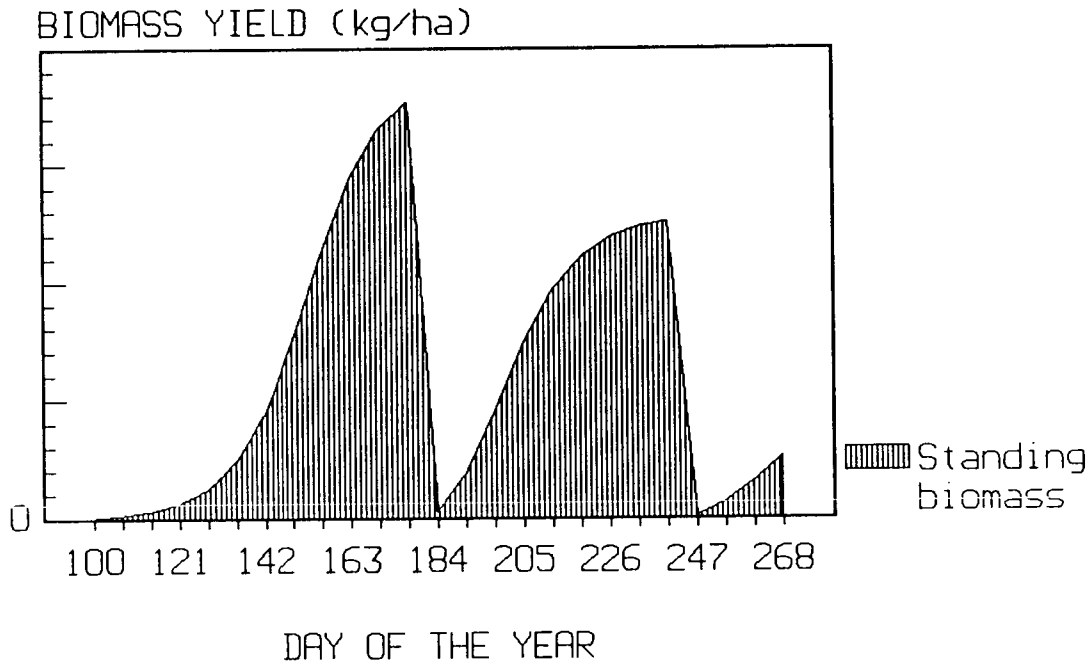
Figure 28. Example output from HERBIE: simulation of a hypothetical biomass crop under a two-cut system



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V. Appendices

Appendix A. Fertility Treatments

Soil	Species	Year*	Fertilizer Applied** 1	2	3
			(kg ha^{-1})		
Collamer	Alfalfa-bromegrass	1985			
		1986	0-34-22	0-67-45	0-134-90
		1987	0-11-34	0-22-67	0-45-134
		1988	0-11-34	0-22-67	0-45-134
	Flatpea	1985			
		1986	0-34-22	0-67-45	0-134-90
		1987	0-06-22	0-11-45	0-22-90
		1988	0-07-22	0-11-45	0-22-90
	Switchgrass	1985			
		1986	22-06-22	45-11-45	90-11-45
		1987	34-06-14	67-11-28	(134)-11-28
		1988	34-06-14	67-11-28	134-11-28
	Timothy-redtop red clover	1985			
		1986	0-34-22	0-67-45	0-134-90
		1987	0-06-22	0-11-45	0-22-90
		1988	0-06-22	0-11-45	0-22-90
Collamer-e	Alfalfa-bromegrass	1985			
		1986	0-34-22	0-67-45	0-134-90
		1987	0-11-34	0-22-67	0-45-134
		1988	0-11-34	0-22-67	0-45-134
	Flatpea	1985			
		1986	0-34-22	0-67-45	0-134-90
		1987	0-06-22	0-11-28	0-22-90
		1988	0-06-22	0-11-45	0-22-90
	Switchgrass	1985			
		1986	22-06-22	45-11-45	90-11-45
		1987	34-06-14	67-11-28	(134)-11-28
		1988	34-06-14	67-11-28	134-11-28
	Timothy-redtop-red clover	1985			
		1986	0-34-22	0-67-45	0-134-90
		1987	0-06-22	0-11-45	0-22-90
		1988	0-06-22	0-11-45	0-22-90
Erie	Eastern gamagrass	1985			
		1986	34-22-39	67-45-78	134-45-78
		1987	34-22-39	67-45-78	(134)-45-78
		1988	34-22-39	67-45-78	134-45-78

Appendix A. Fertility Treatments (cont.)

Soil	Species	Year*	Fertilizer Applied** 1	2	3
			(kg ha^{-1})		
	Reed canarygrass	1985	0-0-0	22-11-40	44-22-80
		1986	28-17-25	56-34-50	(112)-34-50
		1987	34-17-25	67-34-50	(134)-34-50
		1988	34-17-25	67-34-50	134-34-50
	Sudangrass	1985			
		1986	34-22-39	67-45-78	(134)-45-78
		1987			
		1988			
	Timothy-redtop-red clover	1985	0-0-0	0-40-40	0-80-80
		1986	0-17-34	0-34-67	0-(67)-(134)
		1987	0-17-34	0-34-67	0-67-134
		1988	0-17-34	0-34-67	0-76-134
Erie	Meadow	1985			
		1986	0-0-0	0-0-0	0-0-0
		1987	0-17-11	0-34-22	67-34-22
		1988	0-17-11	0-34-22	67-34-22
Honeoye-e	Alfalfa-bromegrass	1985	0-0-0	0-34-11	0-67-22
		1986	0-11-22	0-22-45	0-(45)-(90)
		1987	0-11-22	0-22-45	0-45-90
		1988	0-11-22	0-22-45	0-45-90
	Flatpea	1985	0-0-0	11-22-22	22-45-45
		1986	0-06-11	0-11-22	0-22-45
		1987	0-06-11	0-11-22	0-22-45
		1988	0-06-11	0-11-22	0-22-45
	Kale	1985	0-0-0	56-56-56	112-112-112
		1986	56-22-22	112-45-45	(224)-45-45
		1987			
		1988			
	Sudangrass	1985			
		1986			
		1987	67-34-34	67-34-34	67-34-34
		1988	67-34-34	67-34-34	67-34-34
	Switchgrass	1985	0-0-0	22-06-11	45-11-22
		1986	28-07-11	56-11-22	(112)-11-22
		1987	34-06-11	67-11-22	(134)-11-22
		1988	34-06-11	67-11-22	134-11-22

Appendix A. Fertility Treatments (cont.)

Soil	Species	Year*	Fertilizer Applied** 1	2	3
			(kg ha^{-1})		
	Timothy-redtop-red clover	1985	0-0-0	0-34-11	0-67-22
		1986	0-06-11	0-11-22	0-22-45
		1987	0-11-22	0-22-45	0-45-90
		1988	0-06-11	0-11-22	0-22-45
	F. brassica	1985			
		1986			
		1987	34-34-34	34-34-34	34-34-34
		1988	112-0-0	112-0-0	112-0-0
Kendaia	Kale	1985			
		1986	56-34-34	112-67-67	(224)-67-67
		1987	112-67-67*	112-67-67	224-67-67
		1988			
	Sudangrass	1985			
		1986	34-34-34	67-67-67	(134)-67-67
		1987	67-67-67	67-67-67	67-67-67
		1988	67-67-67	67-67-67	67-67-67
	F. brassica	1985			
		1986			
		1987	34-67-67	34-67-67	34-67-67
		1988	112-0-0	112-0-0	112-0-0
Madalin	Kale	1985	0-0-0	56-56-56	112-112-112
		1986	56-39-22	112-78-45	224-78-45
		1987			
		1988			
	Meadow	1985	0-0-0	0-22-22	0-45-45
		1986	0-28-22	0-56-45	56-56-45
		1987	0-28-22	0-56-45	67-56-45
		1988	0-28-22	0-56-45	67-56-45
	Reed canarygrass	1985	0-0-0	22-6-11	45-11-22
		1986	28-28-13	56-56-28	112-56-56
		1987	34-28-14	67-56-28	(134)-56-28
		1988	34-28-14	67-56-28	134-56-28
	Switchgrass	1985	0-0-0	22-06-11	45-11-22
		1986	28-28-13	56-56-28	112-56-56
		1987	34-28-14	67-56-28	(134)-56-28
		1988	34-28-14	67-56-28	134-56-28

Appendix A. Fertility Treatments (cont.)

Soil	Species	Year*	Fertilizer Applied** 1	2	3
				(kg ha^{-1})	
	Timothy-redtop	1985	0-0-0	0-34-11	0-67-22
	redtop-	1986	0-28-22	0-56-90	0-112-90
	red clover	1987	0-28-22	0-56-45	0-112-90
		1988	0-28-22	0-56-45	0-112-90
Mardin	Flatpea	1985	0-0-0	11-22-22	22-45-45
		1986	0-17-34	0-34-67	0-(67)-(134)
		1987	0-17-34	0-34-67	0-67-134
		1988	0-17-34	0-34-67	0-67-134
	Kale	1985	0-0-0	56-56-56	112-112-112
		1986	60-39-39	112-78-78	(224)-78-78
		1987	112-78-78	112-78-78	(224)-78-78
		1988			
	Sudangrass	1985			
		1986			
		1987			
		1988	67-34-34	67-34-34	67-34-34
	Switchgrass	1985	0-0-0	22-17-34	45-34-67
		1986	28-17-23	56-34-50	(112)-34-50
		1987	34-17-25	67-34-50	(134)-34-50
		1988	34-17-25	67-34-50	134-34-50
	Timothy-	1985	0-0-0	0-43-34	0-84-67
	redtop-	1986	0-17-34	0-34-67	0-(67)-(134)
	red clover	1987	0-17-34	0-34-67	0-67-134
		1988	0-67-134	34-67-134	67-67-134
	F. brassica	1985			
		1986		34-67-67	
		1987			116-0-0
		1988		34-67-67	
Rhinebeck	Flatpea	1985	0-0-0	11-22-22	22-45-45
		1986	0-28-22	0-56-90	0-(112)-(90)
		1987	0-28-22	0-56-45	0-112-90
		1988			
	Kale	1985	0-0-0	56-56-56	112-112-112
		1986	56-39-22	112-78-45	(224)-78-45
		1987			
		1988			

Appendix A. Fertility Treatments (cont.)

Soil	Species	Year*	Fertilizer Applied** 1	2	3
			(kg ha^{-1})		
	Meadow	1985	0-0-0	0-22-22	0-45-45
		1986	0-0-0	0-56-45	56-56-45
		1987	0-28-22	0-56-45	67-56-45
		1988	0-28-22	0-56-45	67-56-45
	Reed canarygrass	1985	0-0-0	22-6-11	45-11-22
		1986	28-28-13	56-56-13	(112)-56-56
		1987	34-28-14	67-56-28	134-56-28
		1988	34-28-14	67-56-28	134-56-28
	Switchgrass	1985	0-0-0	22-6-11	45-11-22
		1986	28-28-13	56-56-28	(112)-56-56
		1987	34-28-14	67-56-28	134-56-28
		1988	34-28-14	67-56-28	134-56-28
	Timothy-redtop-red clover	1985	0-0-0	0-34-11	0-67-22
		1986	0-28-22	0-56-90	0-(112)-(90)
		1987	0-28-22	0-56-45	0-112-90
		1988	0-28-22	0-56-45	0-112-90

*1989 fertility treatments were exactly the same as 1988.
() half of treatment applied early in growing season, the second half late in a split application
**Applied as N-P_2O_5-K_2O

Appendix B: Pest Control Measures

Soil	Species	Date	Treatment[a]
Collamer	Alfalfa-bromegrass	6-13-86	2
		6-27-86	6
		7-04-86	6
		7-25-86	6
		6-02-87	6
	Flatpea	7-25-86	11
		4-26-89	13
	Switchgrass	6-27-86	3
		7-25-86	11
		8-13-86	1
		4-21-87	3
		10-19-87	7
		4-14-89	3
	Timothy-redtop red clover	6-13-86	2
		7-25-86	12
Collamer-e	Alfalfa-bromegrass	6-13-86	2
		6-27-86	6
		7-04-86	6
		7-25-86	6
		6-02-87	6
	Flatpea	7-25-86	11
		4-26-89	13
	Switchgrass	6-27-86	3
		7-25-86	11
		8-13-86	1
		4-21-87	3
		10-19-87	7
		4-14-89	3
	Timothy-redtop red clover	6-13-86	2
		7-25-86	12
Erie	Eastern gamagrass	7-10-86	1
		5-12-87	3

Appendix B: Pest Control Measures (cont.)

Soil	Species	Date	Treatment[a]
	Reed canarygrass	7-10-86	1
	Sudangrass	7-10-86	1
Honeoye-e	Alfalfa-bromegrass	8-05-85	6
	Flatpea	4-26-89	13
	Kale	7-18-85	9
		7-30-85	9
		9-04-85	9
		6-25-86	6
		9-15-86	8
	Sudangrass	5-29-87	8
		9-01-88	8
	Switchgrass	5-27-86	3
		4-11-89	3
	F. brassica	9-01-87	5
Kendaia	F. brassica	9-07-88	10
		9-07-88	5
Madalin	Kale	9-17-85	6
		6-17-86	9
		7-08-86	9
		7-27-86	9
		8-20-86	6
	Switchgrass	8-20-86	4
		4-29-86	3
		5-09-89	3
Mardin	All plots	7-12-85	12
	Flatpea	4-26-89	13

Appendix B: Pest Control Measures (cont.)

Soil	Species	Date	Treatment[a]
	Kale	5-27-86	6
		6-18-86	9
		7-03-86	6
		8-01-86	9
		8-15-86	6
		5-12-87	10
		5-13-87	5
		7-28-87	9
	Sudangrass	7-18-88	1
		9-01-88	8
	Switchgrass	8-01-85	2
		5-13-86	3
		6-30-86	1
		8-08-86	3
		10-20-86	7
		5-12-87	3
		4-14-89	3
	Timothy-redtop red clover	8-01-85	2
	F. brassica	9-11-86	5,10
		5-18-87	8
		9-07-88	5,10
Rhine	Flatpea	5-09-89	13
Switchgrass		4-29-87	3
		5-09-89	3

[a]Treatment Codes:

1) 2,4-D 1 pt/A
2) 2,4-DB 2 qt/A
3) Atrazine 1 lb/A
4) Banvel 1 qt/A
5) Counter 5g 5 lb/A
6) malathion/methoxychlor 2 qt/A
7) Paraquat 1 qt/A
8) Roundup 1 qt/A
9) Sevin 2 lb/A
10) Treflan .75 qt/A
11) Mown to 6"
12) Mown to 12"
13) Poast .2 lb/A

Appendix C: Harvest Dates

1985 Harvest Dates

Soil	Species	1st cut
Erie	Timothy-redtop-red clover	8-27
Honeoye-e	Alfalfa-bromegrass	8-28
	Kale	11-05
	Timothy-redtop-red clover	8-28
Madalin	Kale	11-21
Mardin	Kale	10-28
	Timothy-redtop-red clover	8-27
Rhinebeck	Kale	11-21

Appendix C: Harvest Dates (cont.)

1986 Harvest Dates

Soil	Species	System	1st cut	2nd cut	3rd cut
Collamer	Alfalfa-	C	7-24		
	bromegrass	X	7-24		
	Switchgrass	C	7-25		
		X	7-25		
	Timothy-redtop-	C	8-12		
	red clover	X	8-12		
Collamer-e	Alfalfa-	C	7-16		
	bromegrass	X	7-16		
	Timothy-redtop-	C	7-23		
	red clover	X	7-23		
Erie	Reed canarygrass	C	6-09	8-28	
		X	6-26		
	Sudangrass	C	7-29		
		X	10-06		
	Timothy-redtop-	C	6-09	8-28	
	red clover	X	6-26	8-28	
Erie	Meadow	C	6-10	10-08	
		X	7-01		
Honeoye-e	Alfalfa-	C	5-28	7-15	9-08
	bromegrass	X		6-19	9-08
	Flatpea	C	8-05		
		X	8-05		
	Kale		9-08		
	Switchgrass	C	8-05		
		X	8-05		
	Timothy-redtop-	C	5-28	7-15	9-18
	red clover	X	6-24	9-18	
Kendaia	Kale		11-12		
	Sudangrass	C	8-04	9-10	
		X	9-10		
Madalin	Kale		11-07		
	Meadow	C	6-17	9-24	
		X	7-08		

Appendix C: Harvest Dates (cont.)

1986 Harvest Dates (cont.)

Soil	Species	System	1st cut	2nd cut	3rd cut
	Reed canarygrass	C	7-08	9-24	
		X	9-24		
	Timothy-redtop-	C	6-16	9-24	
	red clover	X	7-08	9-24	
Mardin	Flatpea	C	8-06		
		X	8-06		
	Kale		11-03		
	Switchgrass	C	7-29		
		X	7-29		
	Timothy-redtop-	C	6-09	8-28	
	red clover	X	6-26	8-28	
Rhinebeck	Kale		11-07		
	Meadow	C	6-17	8-26	
		X	7-08		
	Reed canarygrass	C	7-08	9-24	
		X	9-24		
	Timothy-redtop-	C	6-16	8-26	
	red clover	X	7-08	8-26	

Appendix C: Harvest Dates (cont.)

1987 Harvest Dates

Soil	Species	System	1st cut	2nd cut	3rd cut
Collamer	Alfalfa-	C	6-01	7-16	9-14
	bromegrass	X	6-11	9-14	
	Flatpea		8-07		
	Switchgrass		8-17		
	Timothy-redtop-	C	6-05	7-16	9-23
	red clover	X	7-06	9-23	
Collamer-e	Alfalfa-	C	6-01	7-16	9-04
	bromegrass	X	6-11	9-04	
	Flatpea		8-07		
	Switchgrass		8-17		
	Timothy-redtop-	C	6-05	7-15	9-16
	red clover	X	7-06	9-16	
Erie	E. gamagrass		10-02		
	Reed canarygrass	C	6-09	10-05	
		X	7-13		
	Timothy-redtop-	C	6-23		
	red clover	X	7-13		
Erie	Meadow	C	6-25		
		X	7-16		
Honeoye-e	Alfalfa-	C	5-29	7-14	9-10
	bromegrass	X	6-10	9-10	
	Flatpea		8-04		
	Sudangrass		8-25		
	Switchgrass		8-04		
	Timothy-redtop-	C	6-10	10-06	
	red clover	X	7-14		
Kendaia	Kale		10-22		
	Sudangrass		8-24		
Madalin	Meadow	C	6-17		
		X	7-07		
	Reed canarygrass	C	6-18		
		X	7-07		
	Switchgrass		8-18		
	Timothy-redtop-	C	6-17		
	red clover	X	7-07		
Mardin	Flatpea		8-07		
	Kale		10-27		
	Switchgrass		8-06		

Appendix C: Harvest Dates (cont.)

1987 Harvest Dates (cont.)

Soil	Species	System	1st cut	2nd cut	3rd cut
	Timothy-redtop-	C	6-09	9-03	
	red clover	X	6-23	9-03	
Rhinebeck	Flatpea		8-18		
	Meadow	C	6-17		
		X	7-07		
	Reed canarygrass	C	6-17		
		X	7-07		
	Switchgrass		8-18		
	Timothy-redtop-	C	6-17		
	red clover	X	7-07		

Appendix C: Harvest Dates (cont.)

1988 Harvest Dates

Soil	Species	System	1st cut	2nd cut	3rd cut
Collamer	Alfalfa-	C	6-09	8-03	9-14
	bromegrass	X	7-12	9-14	
	Flatpea		8-08		
	Switchgrass		8-12		
	Timothy-redtop-	C	7-12	9-19	
	red clover	X	7-28	9-19	
Collamer-e	Alfalfa-	C	6-09	7-28	9-14
	bromegrass	X	7-08	9-14	
	Flatpea		8-08		
	Switchgrass		8-12		
	Timothy-redtop-	C	6-09	9-19	
	red clover	X	7-28	9-19	
Erie	E. gamagrass		9-26		
	Reed canarygrass	C	6-28	9-12	
		X	7-13	9-12	
	Timothy-redtop-	C	7-13		
	red clover	X	8-02		
Erie	Meadow	C	7-14		
		X	8-01		
Honeoye-e	Alfalfa-	C	6-03	8-09	9-07
	bromegrass	X	7-11	9-07	
	Flatpea		8-09		
	Forage brassica		6-01		
	Sudangrass		8-31		
	Switchgrass		8-16		
	Timothy-redtop-	C	7-11		
	red clover	X	8-01		
Madalin	Meadow	C	7-06	9-15	
		X	7-26		
	Reed canarygrass	C	7-06	9-15	
		X	7-26		
	Switchgrass		8-23		
	Timothy-redtop-	C	7-06		
	red clover	X	7-26		
Mardin	Flatpea		8-10		
	Sudangrass		8-22		
	Switchgrass		8-19		
	Timothy-redtop-	C	6-27	9-12	
	red clover	X	7-15	9-12	

Appendix C: Harvest Dates (cont.)

1988 Harvest Dates (cont.)

Soil	Species	System	1st cut	2nd cut	3rd cut
Rhinebeck	Flatpea		8-23		
	Meadow	C	7-06	9-15	
		X	7-26		
	Reed canarygrass	C	7-06	9-15	
		X	7-26		
	Switchgrass		8-23		
	Timothy-redtop-	C	7-06		
	red clover	X	7-26		

C = conventional management system
X = lax management system

Appendix C: Harvest Dates (cont.)

1989 Harvest Dates

Soil	Species	System	1st cut	2nd cut	3rd cut
Collamer	Alfalfa-	C	6-23	7-24	9-18
	bromegrass	X	6-23	9-18	
	Flatpea		8-14		
	Switchgrass		8-11		
	Timothy-redtop-	C	6-19	8-24	
	red clover	X	7-06	8-24	
Collamer-e	Alfalfa-	C	6-09	7-24	9-18
	bromegrass	X	6-23	9-18	
	Flatpea		8-14		
	Switchgrass		8-14		
	Timothy-redtop-	C	6-19	8-24	
	red clover	X	7-06	8-24	
Erie	E. gamagrass		9-19		
	Reed canarygrass	C	6-26	8-31	
		X	7-12		
	Timothy-redtop-	C	6-26	8-31	
	red clover	X	7-12	8-31	
Erie	Meadow	C	6-19		
		X	7-03		
Honeoye-e	Alfalfa-	C	6-07	7-24	9-13
	bromegrass	X	6-22	9-13	
	Flatpea		8-17		
	Forage brassica		6-22		
	Switchgrass		8-17		
	Timothy-redtop-	C	6-12	9-13	
	red clover	X	6-27	9-13	
Kendaia	Forage brassica		6-22		
	Sudangrass		8-25		
Madalin	Meadow	C	6-29	9-05	
		X	7-11		
	Reed canarygrass	C	6-29	9-05	
		X	7-11		
	Switchgrass		8-15		
	Timothy-redtop-	C	6-29	9-05	
	red clover	X	7-11	9-05	
Mardin	Flatpea		8-14		
	Switchgrass		8-11		
	Timothy-redtop-	C	6-21	8-24	
	red clover	X	7-07	8-24	

Appendix C: Harvest Dates (cont.)

1989 Harvest Dates

Soil	Species	System	1st cut	2nd cut	3rd cut
Rhinebeck	Meadow	C	6-29	9-04	7-11
	Reed canarygrass	C	6-29	9-04	
		X	7-11		
	Switchgrass		8-15		
	Timothy-redtop-	C	6-29	9-04	
	red clover	X	7-11		

C = conventional management system
X = lax management system

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth).

Soil	Species	Fert. Level		pH	Soil Nutrient P	K	Mg	Ca
					mg kg soil^{-1}			
Collamer	Alfalfa-bromegrass	1	Pre	6.56	5.0	33.0	52.4	1535
			Post	6.67	4.0	29.5	43.4	1546
			Diff	0.11	-1.0	-3.5	-9.0	11
		2	Pre	6.37	6.2	35.9	50.6	1604
			Post	6.32	5.0	34.2	42.6	1530
			Diff	-.05	-1.1	-1.6	-8.0*	-74
		3	Pre	6.67	6.4	40.6	51.5	1591
			Post	6.67	5.2	41.0	40.7	1541
			Diff	-.01	-1.2	0.4	-10.8*	-50
	Flatpea	1	Pre	6.85	6.1	35.3	50.0	1655
			Post	6.56	3.2	30.8	36.6	1340
			Diff	-.28	-3.0	-4.5	-13.4*	-315
		2	Pre	6.91	7.7	41.5	52.5	1726
			Post	6.58	5.7	39.0	41.8	1529
			Diff	-.33	-2.0	-2.5	-10.8*	-197
		3	Pre	6.80	6.9	48.9	51.4	1682
			Post	6.52	6.7	49.8	43.3	1539
			Diff	-.28	-0.3	0.9	-8.1	-143
	Switchgrass	1	Pre	6.92	7.3	43.0	48.3	1684
			Post	6.88	5.5	32.5	35.5	1588
			Diff	-.05	-1.9	-10.5*	-12.8*	-96
		2	Pre	6.83	6.8	45.6	46.3	1665
			Post	6.68	5.6	33.3	34.8	1465
			Diff	-.15	-1.2	-12.4	-11.4	-200
		3	Pre	6.91	7.0	46.3	48.9	1743
			Post	6.58	5.8	40.0	35.5	1461
			Diff	-.34	-1.2	-6.3*	-13.3*	-283*
	Timothy-redtop-red clover	1	Pre	6.59	5.5	35.1	50.0	1595
			Post	6.72	3.8	27.0	37.7	1478
			Diff	0.13	-1.7	-8.1	-12.3	-118*
		2	Pre	6.67	6.4	37.1	48.6	1607
			Post	6.75	4.6	30.0	37.0	1589
			Diff	0.08	-1.7	-7.1	-11.6	-17

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level	pH	Soil Nutrient P	K	Mg	Ca
				mg kg soil^{-1}			
		3 Pre	6.75	6.4	40.9	47.6	1676
		Post	6.72	5.7	36.8	37.6	1599
		Diff	**-.03**	**-0.7**	**-4.1**	**-10.0***	**-77**
Collamer-e	Alfalfa-bromegrass	1 Pre	6.72	6.2	36.3	92.4	1690
		Post	6.71	5.0	30.5	60.3	1536
		Diff	**-.02**	**-1.2**	**-5.8***	**-32.1**	**-154**
		2 Pre	6.59	6.2	44.6	81.5	1667
		Post	6.77	4.7	35.0	57.2	1505
		Diff	**0.18**	**-1.5***	**-9.6***	**-24.3**	**-163**
		3 Pre	6.75	7.0	45.4	93.4	1937
		Post	6.75	6.7	38.0	67.1	1687
		Diff	**0.00**	**-0.3**	**-7.4**	**-26.3**	**-250**
	Flatpea	1 Pre	6.45	6.5	39.0	71.0	1599
		Post	6.61	4.3	37.8	49.5	1359
		Diff	**0.16**	**-2.3***	**-1.3**	**-21.5**	**-240**
		2 Pre	6.50	6.3	41.6	70.9	1588
		Post	6.42	4.8	46.3	55.4	1373
		Diff	**-0.08**	**-1.5***	**4.6**	**-15.5**	**-215**
		3 Pre	6.51	6.2	44.6	74.1	1725
		Post	6.57	5.3	58.3	52.2	1416
		Diff	**0.05**	**-0.9**	**13.6**	**-21.9**	**-309**
	Switchgrass	1 Pre	6.60	5.0	41.1	74.1	1744
		Post	6.71	4.4	36.0	55.7	1542
		Diff	**0.10**	**-0.6***	**-5.1**	**-18.4**	**-203**
		2 Pre	6.56	5.7	41.3	75.0	1653
		Post	6.51	4.2	36.3	54.6	1398
		Diff	**-.05**	**-1.4**	**-5.0**	**-20.4**	**-255**
		3 Pre	6.56	5.3	51.5	73.9	1548
		Post	6.57	4.5	37.3	50.3	1384
		Diff	**0.01**	**-0.9**	**-14.3***	**-23.6**	**-164**
	Timothy-redtop-red clover	1 Pre	6.58	5.5	37.5	71.3	1590
		Post	6.72	4.5	39.8	51.7	1466
		Diff	**0.14**	**-0.9**	**-7.8***	**-19.6**	**-123**

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level		pH	Soil Nutrient P	K	Mg	Ca
					mg kg soil^{-1}			
		2	Pre	6.70	5.8	36.2	82.3	1634
			Post	6.66	4.2	31.7	43.4	1466
			Diff	**-.04**	**-1.6**	**-4.5**	**-38.9**	**-169**
		3	Pre	6.47	6.2	45.8	78.4	1813
			Post	6.70	5.5	31.3	53.2	1572
			Diff	**0.22**	**-0.7**	**-14.5***	**-25.2**	**-241**
Erie	Eastern gamagrass	1	Pre	6.85	9.8	45.0	173.5	2679
			Post	6.89	2.6	24.5	177.7	2643
			Diff	**0.04**	**-7.3**	**-20.5**	**4.2**	**-36**
		2	Pre	6.80	4.8	68.0	185.0	2541
			Post	6.91	2.3	24.0	176.5	2547
			Diff	**0.10**	**-2.5**	**-44.0**	**-8.5**	**6**
		3	Pre	6.70	4.7	44.0	185.5	2621
			Post	6.89	4.7	30.5	180.7	2511
			Diff	**0.19**	**-0.1**	**-13.5**	**-4.8**	**-110**
	Meadow	1	Pre	6.08	1.6	74.0	99.0	1598
			Post	6.20	1.7	43.5	102.4	1614
			Diff	**0.12**	**0.1**	**-30.5**	**3.4**	**16**
		2	Pre	6.36	1.5	83.1	102.0	1900
			Post	6.49	4.8	50.0	110.3	2127
			Diff	**0.13**	**3.4***	**-33.1***	**8.3**	**226**
		3	Pre	6.19	1.5	91.4	104.8	1792
			Post	6.17	2.1	58.5	95.0	1705
			Diff	**-.01**	**0.5**	**-32.9**	**-9.8**	**-87**
	Reed canarygrass	1	Pre	6.76	7.0	36.0	175.6	2606
			Post	6.97	2.5	27.0	157.4	2478
			Diff	**0.20**	**-4.5**	**-9.0***	**-18.2**	**-128**
		2	Pre	6.66	5.8	34.3	193.6	2506
			Post	7.01	3.5	27.5	168.7	2627
			Diff	**0.35**	**-2.4**	**-6.8**	**-24.9**	**121**
		3	Pre	6.63	5.4	40.0	205.0	2569
			Post	6.97	2.4	25.0	162.4	2476
			Diff	**0.34**	**-3.0**	**-15.0***	**-42.6**	**-93**

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level		pH	Soil Nutrient P	K	Mg	Ca
					mg kg soil^{-1}			
	Timothy-redtop-red clover	1	Pre	6.72	4.8	34.1	181.8	2531
			Post	6.91	2.9	23.8	175.7	2551
			Diff	**0.19**	**-1.9***	**-10.4***	**-6.0**	**20**
		2	Pre	6.51	4.3	31.6	188.0	2538
			Post	6.78	2.1	24.0	177.2	2415
			Diff	**0.27**	**-2.2***	**-7.6***	**-10.8**	**-123**
		3	Pre	6.72	6.4	36.1	188.5	2498
			Post	6.91	3.5	26.0	191.4	2566
			Diff	**0.18**	**-2.9**	**-10.1**	**2.9**	**68**
Honeoye-e	Alfalfa-bromegrass	1	Pre	6.95	6.4	84.1	271.6	1441
			Post	7.10	2.2	36.3	249.5	1455
			Diff	**0.15**	**-4.2***	**-47.9***	**-22.1**	**13**
		2	Pre	7.11	7.5	82.6	270.9	1542
			Post	7.33	3.2	38.5	268.8	1583
			Diff	**0.21**	**-4.3***	**-44.1***	**-2.1**	**42**
		3	Pre	7.06	8.3	94.5	274.0	1582
			Post	7.20	4.2	38.5	254.1	1535
			Diff	**0.13**	**-4.1**	**-56.0***	**-19.9**	**-47**
	Flatpea	1	Pre	7.29	9.9	81.5	268.6	1706
			Post	7.40	4.0	48.8	256.6	1671
			Diff	**0.12**	**-5.9***	**-32.8***	**-12.1**	**-35**
		2	Pre	7.35	9.5	80.0	287.6	1727
			Post	7.39	5.4	51.0	260.9	1671
			Diff	**0.04**	**-4.2**	**-29.0***	**-26.7**	**-56**
		3	Pre	7.31	8.5	68.8	282.5	1677
			Post	7.50	5.7	51.8	259.6	1704
			Diff	**0.18**	**-2.8***	**-17.0**	**-22.9**	**27**
	Forage brassica/ Sudangrass	2	Pre	7.17	5.3	84.3	331.3	1590
			Post	7.32	5.2	46.8	286.4	1572
			Diff	**0.15**	**-0.1**	**-37.5***	**-44.9**	**-18**
	Switchgrass	1	Pre	7.10	6.7	87.3	293.0	1555
			Post	7.36	4.5	53.8	271.6	1522
			Diff	**0.27**	**-2.2***	**-33.5**	**-21.4**	**-33**

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level		pH	Soil Nutrient P	K	Mg	Ca
					mg kg soil^{-1}			
		2	Pre	7.24	6.7	78.3	271.5	1685
			Post	7.43	5.6	59.0	255.9	1625
			Diff	**0.19**	**-1.1**	**-19.3**	**-15.6**	**-60**
		3	Pre	7.16	6.8	75.3	292.5	1594
			Post	7.34	3.8	45.3	268.9	1510
			Diff	**0.18**	**-3.0**	**-30.0***	**-23.6**	**-84**
	Timothy-	1	Pre	7.22	8.5	74.6	259.0	1646
	redtop-		Post	7.49	3.7	41.3	264.5	1668
	red clover		**Diff**	**0.26**	**-4.8***	**-33.4***	**5.5**	**23**
		2	Pre	7.21	8.4	91.0	291.1	1712
			Post	7.48	4.1	46.8	258.1	1622
			Diff	**0.27**	**-4.3***	**-44.3**	**-33.1**	**-91**
Honeoye-e	Timothy-	3	Pre	7.20	9.1	82.6	266.6	1822
	redtop-		Post	7.54	5.6	52.5	242.7	1854
	red clover		**Diff**	**0.34**	**-3.5***	**-30.1***	**-24.0**	**32**
Madalin	Meadow	1	Pre	6.95	0.6	64.4	513.5	3584
			Post	7.02	0.5	51.5	508.1	3595
			Diff	**0.07**	**-0.1**	**-12.9***	**-5.4**	**12**
		2	Pre	6.81	0.6	62.3	491.8	3269
			Post	6.89	0.5	53.5	489.1	3553
			Diff	**0.08**	**-0.1**	**-8.8**	**-2.6**	**285**
		3	Pre	6.94	0.9	71.8	487.8	3213
			Post	7.01	0.7	53.5	469.7	3351
			Diff	**0.07**	**-0.2**	**-18.3**	**-18.1**	**138**
	Reed	1	Pre	6.99	0.5	54.9	496.5	3509
	canarygrass		Post	7.01	0.5	51.8	507.1	3588
			Diff	**0.02**	**-0.1**	**-3.1**	**10.6**	**79**
		2	Pre	7.00	0.5	54.8	504.8	3625
			Post	7.00	0.5	50.8	493.0	3686
			Diff	**0.00**	**0.0**	**-4.0**	**-11.8**	**61**
		3	Pre	6.95	0.5	56.0	488.6	3505
			Post	6.98	0.7	46.0	469.0	3578
			Diff	**0.03**	**0.1**	**-10.0**	**-19.6**	**73**

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level	pH	Soil Nutrient P	K	Mg	Ca
				mg kg soil^{-1}			
	Switchgrass	1 Pre	7.08	0.5	61.6	557.1	3910
		Post	7.11	0.5	54.5	534.9	3787
		Diff	**0.03**	**-0.0**	**-7.1**	**-22.2**	**-123**
		2 Pre	7.05	0.5	59.9	573.0	4122
		Post	7.14	0.5	52.5	526.0	3880
		Diff	**0.09**	**0.0**	**-7.4**	**-47.0**	**-242**
		3 Pre	7.05	0.6	70.4	529.4	3756
		Post	7.07	0.5	51.0	517.2	3787
		Diff	**0.02**	**-0.1**	**-19.4***	**-12.2**	**31**
	Timothy-redtop-red clover	1 Pre	7.10	0.5	65.6	582.4	3897
		Post	7.04	0.4	52.5	572.4	3960
		Diff	**-.06**	**-0.1***	**-13.1**	**-10.0**	**63**
		2 Pre	7.09	0.6	61.0	595.0	3880
		Post	7.11	0.6	49.8	552.4	3914
		Diff	**0.02**	**-0.1**	**-11.3***	**-42.6**	**35**
Madalin	Timothy-redtop-red clover	3 Pre	7.03	0.6	57.8	552.3	3800
		Post	7.11	1.2	47.5	562.3	4017
		Diff	**0.09**	**0.6***	**-10.3***	**10.0**	**217**
Mardin	Flatpea	1 Pre	5.56	1.5	57.6	23.9	934
		Post	6.91	1.4	56.5	34.4	1579
		Diff	**1.34***	**-0.1**	**-1.1**	**10.5**	**645**
		2 Pre	5.61	1.6	63.0	24.5	959
		Post	6.85	1.6	62.8	32.0	1557
		Diff	**1.24***	**0.0**	**-0.3**	**7.5**	**598***
		3 Pre	5.56	2.0	70.0	24.5	920
		Post	6.87	4.1	116.5	31.8	1550
		Diff	**1.30***	**2.0***	**46.5**	**7.3**	**629***
	Forage brassica/ Sudangrass	2 Pre	5.60	1.1	42.0	68.8	929
		Post	6.93	5.2	82.8	32.2	1635
		Diff	**1.33***	**4.0***	**40.8***	**-36.6**	**706***
	Switchgrass	1 Pre	5.50	2.1	63.0	23.3	890
		Post	6.91	3.8	69.8	28.2	1717
		Diff	**1.41***	**1.7**	**6.8**	**5.0**	**827***

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level		pH	Soil Nutrient P	K	Mg	Ca
					mg kg soil^{-1}			
		2	Pre	5.56	2.3	61.5	28.8	941
			Post	6.95	4.9	84.0	32.6	1815
			Diff	**1.39***	**2.6**	**22.5**	**3.9**	**874***
		3	Pre	5.58	1.7	56.4	22.4	917
			Post	6.77	3.9	67.0	31.6	1610
			Diff	**1.20***	**2.2**	**10.6**	**9.2**	**693***
	Timothy-	1	Pre	5.50	1.8	71.8	27.0	940
	redtop-		Post	6.66	3.1	68.7	31.4	1522
	red clover		**Diff**	**1.16***	**1.3**	**-3.1**	**4.4**	**582***
		2	Pre	5.53	2.1	64.3	25.8	938
			Post	6.68	3.0	66.3	30.3	1413
			Diff	**1.16***	**0.8**	**2.0**	**4.5**	**475***
		3	Pre	5.56	2.3	74.6	26.3	964
			Post	6.91	5.1	58.8	31.0	1689
			Diff	**1.34***	**2.9***	**-15.9**	**4.8**	**725***
Rhinebeck	Flatpea	1	Pre	6.95	1.2	40.0	267.0	2077
			Post	7.03	0.9	44.5	288.6	2331
			Diff	**0.08**	**-0.3**	**4.5**	**21.6**	**254**
		2	Pre	7.06	6.0	43.1	260.0	2215
			Post	7.05	4.8	45.3	284.6	2490
			Diff	**-.01**	**-1.2**	**2.1**	**24.6**	**274**
		3	Pre	6.96	2.8	39.0	264.8	2180
			Post	6.96	3.1	50.8	281.9	2304
			Diff	**-0.01**	**0.3**	**11.8***	**17.1**	**124**
	Meadow	1	Pre	6.80	0.5	43.0	290.0	2051
			Post	6.85	0.8	41.8	306.0	2122
			Diff	**0.06**	**0.3**	**-1.3**	**16.0**	**71**
		2	Pre	6.70	0.8	42.9	303.4	1962
			Post	6.83	1.0	41.8	313.7	2106
			Diff	**0.13**	**0.2**	**-1.1**	**10.3**	**144**
		3	Pre	6.63	0.7	48.9	292.3	2094
			Post	6.78	1.0	43.5	293.5	2265
			Diff	**0.15**	**0.3**	**-5.4**	**1.3**	**171**

Appendix D. Changes in Soil Nutrient Status (0-15 cm depth). (cont.)

Soil	Species	Fert. Level		pH	Soil Nutrient P	K	Mg	Ca
					mg kg soil^{-1}			
	Reed canarygrass	1	Pre	7.04	1.4	36.8	307.4	2146
			Post	7.00	1.1	40.8	286.5	2434
			Diff	**-.04**	**-0.4**	**4.0***	**-20.9**	**288**
		2	Pre	7.08	4.0	43.5	292.3	2263
			Post	7.03	3.0	40.0	305.1	2857
			Diff	**-.05**	**-1.0**	**-3.5**	**12.8**	**594**
		3	Pre	7.03	2.3	38.3	295.4	2227
			Post	7.00	1.4	35.0	288.6	2344
			Diff	**-.03**	**-0.9**	**-3.3**	**-6.8**	**117**
	Switchgrass	1	Pre	7.04	1.0	37.9	272.1	2175
			Post	7.01	1.4	44.8	288.3	2441
			Diff	**-.02**	**0.4**	**6.9**	**16.1**	**266**
		2	Pre	7.00	1.1	35.9	255.9	2044
			Post	6.91	2.5	37.5	268.1	2323
			Diff	**-.09**	**1.3***	**1.6**	**12.2**	**279**
		3	Pre	6.97	0.9	39.5	268.3	2145
			Post	6.93	1.6	40.0	284.0	2452
			Diff	**-.04**	**0.7**	**0.5**	**15.8**	**307**
	Timothy-redtop-red clover	1	Pre	6.97	0.6	32.1	273.8	2108
			Post	7.04	0.7	38.5	293.0	2308
			Diff	**0.07**	**0.1**	**6.4***	**19.3**	**199**
		2	Pre	6.88	0.9	39.0	290.4	2106
			Post	7.00	1.3	40.8	295.4	2422
			Diff	**0.13**	**0.4**	**1.8**	**5.0**	**316**
		3	Pre	6.92	1.0	34.0	267.9	2017
			Post	7.08	2.8	42.5	295.8	2331
			Diff	**0.15***	**1.8***	**8.5**	**27.9**	**314**

'*' indicates a significant change in the level of a nutrient in the soil based on a T-test comparison (alpha = 0.05) of pre- and post test values.

Appendix E: Computer Modeling Program -- HERB (LEVEL 1.0)

```
'This ACSL version of HERB (LEVEL 1.0) is the initial version of'
'a HERBaceous biomass production simulator for the zone around the'
'Great Lakes.  Programming began in 1987 from a prototype model for'
'alfalfa production named ALSIM 1 (LEVEL ZERO), which is documented'
'in the users manual: Cornell Agron. Mimeo 83-26.'
Initial

'------------------------------------------------ DATA SECTION'
'1983 weather data'
TABLE DHTT,1,14/1., 31., 45.5, 74.5, 105., 135.5, 166.,...
182., 212., 227.5, 258., 288.5, 319., 349.5,...
32., 32., 36., 45., 52., 64., 80., 85., 85., 82., 76.,...
61., 48., 18./
TABLE DLTT,1,14/1., 31., 45.5, 74.5, 105., 135.5, 166.,...
182., 212., 227.5, 258., 288.5, 319., 349.5,...
18., 18., 20., 29., 33., 42., 55., 60., 60., 59., 51.,...
40., 32., 18./
TABLE RPF,1,7/0., 100., 150., 225., 275., 425., 10000.,...
1., .95, .75, .75, .95, 1.25, 1.25/
CONSTANT  DDI=0., BASE=5., SMAFC=180., RPIN=1.
CONSTANT A=5.3, B=-6.7, C=0.5, S=150.
INTEGER I, J, JR, K, YEAR
CONSTANT I=1, J=1
REAL YMAX(20), DDHAR(20), CUTDAY(20)
CONSTANT YMAX=9400.,6600.,18*4000.
CONSTANT DDHAR=400.,600.,18*600.
CONSTANT CUTDAY=158.,195.,244.,17*400.
CONSTANT IDOY=91.,YEAR=1983

      K       =J
      DDN     =DEGDAY/DDHAR(I)
      YPOT2   =YMAX(I)/(1.+EXP(A+B*(DDN**C)))
      LATE    =0.
'LATE is a signal that switches to late-season growth parameters when'

'the first cut is made after July 19 (DOY = 200.)'
      CUT     =0.
      RPIN    =AMAX1(.5,AMIN1(1.,RPIN))
      RPL     =RPIN

End $ ' of Initial '

Dynamic

Derivative

'---------------------------HERBACEOUS CROP GROWTH SECTION'
```

Appendix E: Computer Modeling Program -- HERB (LEVEL 1.0) (cont.)

```
      YLDA     =INTEG(GACT,0.)
      GACT     =GPOT*(1.-CUT)*SPF*RP -YLDA*CUT
      SPF      =AMIN1(1.,SMAFC/S)
      BIOMAS   =INTEG(YLDA*CUT,0.)
     PROCEDURAL (GPOT=YMAX,I,A,B,C,DDN,YPOT1,YPOT2,CUT)
      IF(TT.EQ.T) GOTO 1
'TT is checked to determine if the main program has advanced time (T)'

      YPOT1    =YPOT2
      YPOT2    =YMAX(I)/(1.+EXP(A+B*(DDN**C)))
      GPOT     =AMAX1(YPOT2-YPOT1,0.)
      1..CONTINUE
      TT       =T
     END
      DDN      =DEGDAY/DDHAR(I)
      DEGDAY   =INTEG(HSUM,DDI)
      HSUM     =AMAX1(0.,MEAN-BASE) -DEGDAY*CUT
'HSUM is the daily heat sum'
      MEAN     =(5./9.)*(((DHT + DLT)/2.)-32.)
      DOY      =T+IDOY
'DOY is the day of the year'
'IDOY is the initial DOY'
      DHT      =DHTT(DOY)
'DHT is daily high temperature; DHTT is the DHT table'
      DLT      =DLTT(DOY)
'DLT is daily low temperature; DLTT is the DLT table'

'------------------------------------------ CUTTING SECTION'

     PROCEDURAL (CUT,I,J,RP=CUTDAY,DOY,RPIN,RPL,RPF,DEGDAY)
      IF(TTT.EQ.T) GOTO 2
'TTT is checked to determine if the main program has advanced time (T)'

      CUT      =0.
      LATE     =0.
      IF(CUTDAY(J).EQ.DOY) CUT=1.
      IF(CUTDAY(1).GT.200.AND.CUTDAY(1).EQ.DOY) LATE=1.
      RP1      =AMAX1(0.5,RPL*(1.-CUT),AMIN1(1.,CUT*RPL*RPF(DEGDAY)))
      RP       =ZHOLD(RPIN, CUT.GT.0.0, RP1)
      RPL      =RP1
      J        =J+CUT
      I        =I+CUT+CUT*LATE

      2..CONTINUE
      TTT      =T
     END

End $ ' of Derivative '
```

Appendix E: Computer Modeling Program -- HERB (LEVEL 1.0) (cont.)

```
'----------------------------BIOMASS CHEMICAL COMPOSITION SECTION'

      LP1      =AMIN1(1.,1.374-0.153*ALOG(DEGDAY+1.))
      LP2      =AMIN1(1.,1.926-0.217*ALOG(DEGDAY+1.))
      LP       =RSW(K-2.LT.0.0,LP1,LP2)
      ASCPF     =AMIN1(0.35,1.566+0.00039*DEGDAY-0.267*ALOG(DEGDAY+1.))
       ALCPF    =0.405-0.00018*DEGDAY
      SIVTD    =AMIN1(0.9,1.859-0.202*ALOG(DEGDAY+1.))
      LIVTD    =0.948-6.1E-5*DEGDAY
      SDIG     =SIVTD-(0.3657-0.275*SIVTD)
      LDIG     =LIVTD-(0.3657-0.275*LIVTD)
      ACPF     =ALCPF*LP+ASCPF*(1.-LP)
      ADIGF    =LDIG*LP+SDIG*(1.-LP)
      K        =J
      JR       =J - 1
      IF(CUT.LT.1.) GO TO 3
      WRITE(6,100) YEAR,JR,DOY,DEGDAY
      WRITE(6,101) YLDA,LP,ACPF,ADIGF
      WRITE(6,102) ALCPF,ASCPF,LDIG,SDIG
      3..CONTINUE
      100..FORMAT('      YEAR =',I4,';    CUT =',I2,';    DATE...
 =',F5.0,';    DEGREE DAYS =',F5.0)
      101..FORMAT(' HARVESTED YIELD = ',F5.0,' KG/HA; LEAF, CP,...
 AND DIG FRACTIONS =',3F6.3)
      102..FORMAT(' LEAF CP =',F5.3,'; STEM CP =',F5.3,'; LEAF DIG...
 =',F5.3,'; STEM DIG =',F5.3)

      Algorithm Ialg = 3
      Nsteps    Nstp = 1
      Maxterval Maxt = 1.
      Cinterval Cint = 1.
      Constant  Tstp = 240.
      Termt(T .ge. Tstp)

End $ ' of Dynamic '

Terminal

      RPOT     =AMAX1(0.5,AMIN1(1.,RP*RPF(DEGDAY)))
      I        = 1
      J        = 1
      WRITE(6,106)
      WRITE(6,103) JR,YEAR,BIOMAS
      WRITE(6,104) RPOT
      WRITE(6,105) SMAFC
      WRITE(6,106)
      WRITE(6,106)
      103..FORMAT(' THIS ',I2,'-CUT SYSTEM IN ',I4,' GAVE A TOTAL...
```

Appendix E: Computer Modeling Program -- HERB (LEVEL 1.0) (cont.)

```
 YIELD OF ',F7.0,' KG/HA')
      104..FORMAT(' WITH A WINTER SURVIVAL POTENTIAL OF ',F4.2,'...
 RELATIVE TO THE BEST MANAGEMENT.')
      105..FORMAT(' THE SOIL HAD ',F4.0,' MM OF PLANT AVAILABLE WATER.')
     106..FORMAT(' ')

End $ ' of Terminal '
End $ ' of Program '
```

Appendix F: Computer Modeling Program -- HERBIE

```
'This ACSL program is the current developmental version of the'
'Cornell Agronomy HERBaceous biomass simulator.'
'Date of last change: 9-14-87'
'Time of last change: 14:30'
'Change made by:  GWF'

Initial

'------------------------------------------------ DATA SECTION'

'1983 weather data'
TABLE DHTT,1,14/1., 31., 45.5, 74.5, 105., 135.5, 166.,...
182., 212., 227.5, 258., 288.5, 319., 349.5,...
32., 32., 36., 45., 52., 64., 80., 85., 85., 82., 76.,...
61., 48., 18./
TABLE DLTT,1,14/1., 31., 45.5, 74.5, 105., 135.5, 166.,...
182., 212., 227.5, 258., 288.5, 319., 349.5,...
18., 18., 20., 29., 33., 42., 55., 60., 60., 59., 51.,...
40., 32., 18./
TABLE RPF,1,7/0., 100., 150., 225., 275., 425., 10000.,...
1., .95, .75, .75, .95, 1.25, 1.25/
CONSTANT  DDI=0., BASE=5., SMAFC=180., RPIN=1.
CONSTANT A=5.3, B=-6.7, C=0.5, S=150.
CONSTANT YLDI=10*0.,BIOMI=10*0.
INTEGER I, J, K, N, YEAR
CONSTANT I=1, J=1
REAL YMAX(20), DDHAR(20), CUTDAY(20)
CONSTANT YMAX=9400.,6600.,18*4000.
CONSTANT DDHAR=400.,600.,18*600.
CONSTANT CUTDAY=158.,195.,244.,17*400.
CONSTANT IDOY=91.,YEAR=1983

      K       =J
      DDN     =DEGDAY/DDHAR(I)
      YPOT2   =YMAX(I)/(1.+EXP(A+B*(DDN**C)))
      LATE    =0.
'LATE is a signal that switches to late-season growth parameters when'
'The first cut is made after July 19 (DOY = 200.)'
      CUT     =0.
      RPIN    =AMAX1(.5,AMIN1(1.,RPIN))
      RPL     =RPIN
End $ ' of Initial '

Dynamic

Derivative

'---------------------------HERBACEOUS CROP GROWTH SECTION'
```

Appendix F: Computer Modeling Program -- HERBIE (cont.)

```
ARRAY YLD(10),GACT(10),YLDI(10),BIOMAS(10),HARV(10),BIOMI(10)
      YLD     =INTVC(GACT,YLDI)
      BIOMAS  =INTVC(HARV,BIOMI)
'YLD is an array of current yields of biomass crops (Mg/ha)'
'YLDI is an array of initial YLD values (Mg/ha)'
'GACT is an array of crop growth rates [Mg/(ha*day)]'
'BIOMAS is an array of accumulated yields of biomass crops (Mg/ha)'
'BIOMI is an array of initial BIOMAS values (Mg/ha)'
'HARV is an array of biomass harvesting rates [Mg/(ha*day)]'
     PROCEDURAL (GACT=GPOT,CUT,SPF,RP,YLD)
      GACT(1) =GPOT*(1.-CUT)*SPF*RP - YLD(1)*CUT
      DO 10  N=2,10
      GACT(N) =GACT(1)*.75
      10..CONTINUE
     END
     PROCEDURAL (HARV=YLD,CUT)
      DO 11  N=1,10
      HARV(N)  =YLD(N)*CUT
      11..CONTINUE
     END
      SPF     =AMIN1(1.,SMAFC/S)
     PROCEDURAL (GPOT=YMAX,I,A,B,C,DDN,YPOT1,YPOT2,CUT)
      IF(TT.EQ.T) GOTO 1
'TT is checked to determine if the main program has advanced time (T)'
      YPOT1   =YPOT2
      YPOT2   =YMAX(I)/(1.+EXP(A+B*(DDN**C)))
      GPOT    =AMAX1(YPOT2-YPOT1,0.)
      1..CONTINUE
      TT      =T
     END
      DDN     =DEGDAY/DDHAR(I)
      DEGDAY  =INTEG(HSUM,DDI)
      HSUM    =AMAX1(0.,MEAN-BASE) -DEGDAY*CUT
'HSUM is the daily heat sum'
      MEAN    =(5./9.)*(((DHT + DLT)/2.)-32.)
      DOY     =T+IDOY
'DOY is the day of the year'
'IDOY is the initial DOY'
      DHT     =DHTT(DOY)
'DHT is daily high temperature; DHTT is the DHT table'
      DLT     =DLTT(DOY)
'DLT is daily low temperature; DLTT is the DLT table'

'------------------------------------------ CUTTING SECTION'

     PROCEDURAL (CUT,I,J,RP=CUTDAY,DOY,RPIN,RPL,RPF,DEGDAY)
      IF(TTT.EQ.T) GOTO 2
```

Appendix F: Computer Modeling Program -- HERBIE (cont.)

```
'TTT is checked to determine if the main program has advanced time (T)'
      CUT      =0.
      LATE     =0.
      IF(CUTDAY(J).EQ.DOY) CUT=1.
      IF(CUTDAY(1).GT.200.AND.CUTDAY(1).EQ.DOY) LATE=1.
      RP1      =AMAX1(0.5,RPL*(1.-CUT),AMIN1(1.,CUT*RPL*RPF(DEGDAY)))
      RP       =ZHOLD(RPIN, CUT.GT.0.0, RP1)
      RPL      =RP1
      J        =J+CUT
      I        =I+CUT+CUT*LATE
      2..CONTINUE
      TTT      =T
     END
      Algorithm Ialg = 3
      Nsteps    Nstp = 1
      Maxterval Maxt = 1.
      Cinterval Cint = 7.
      Constant  Tstp = 240.
      Termt(T .ge. Tstp)

End $ ' of Derivative '
End $ ' of Dynamic '

Terminal

      RPOT     =AMAX1(0.5,AMIN1(1.,RP*RPF(DEGDAY)))
      I        = 1
      J        = 1

End $ ' of Terminal '

End $ ' of Program '
```

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