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MASTER

SYSTEMS STUDY OF FUELS FROM GRAINS AND GRASSES

QUARTERLY PROGRESS REPORT
For The Period
July - October 1976

W. Benson
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R. Athey
A. McElroy

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

MRI Project No. 4261-E
Date Published November 15, 1976

Prepared for the United States
Energy Research and Development Administration
Division of Solar Energy
Under Contract No. E (29-2)-3729

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PREFACE

This quarterly progress report is submitted pursuant to Article III, Item No. 2 of the U.S. Energy Research and Development Administration Contract No. E(29-2)-3729 with Midwest Research Institute for a, "Systems Study of Fuels From Grains and Grasses."

The report describes the objectives of the study, the plan by which these objectives will be accomplished, and the progress of the study team to date.

Sincerely,

MIDWEST RESEARCH INSTITUTE

Walter Benson

Walter R. Benson
Project Leader

Approved:

Michael C. Noland

Michael C. Noland, Director
Engineering Sciences Division

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I. INTRODUCTION

A. Background

Recognition of the finite limitations of the earth's supply of fossil energy fuels, and equally disturbing environmental concerns have spurred the search for renewable sources of energy from solar radiation. The United States' increasing dependence upon foreign oil sources and the possible impact on the U.S. economy if those imports are cut off have added another note of urgency to the problem. Total energy independence for the United States may not be attainable, nor even desirable. What is needed; however, is a national plan for energy resource development which will minmize the adverse impacts of abrupt curtailment of any single energy resource, including imports. This goal is implicit in the national plan for energy research, development and demonstration. It is unlikely that a single energy production technology will be developed which will satisfy the total energy needs of the United States. Instead, those energy needs will be met from a multiplicity of resources, of which solar energy is but one.

The production of fuels from biomass is one of the many possibilities of extracting energy from the sun. When one considers energy production in the context of its three major functions--extraction, conversion and distribution--the concept of bioconversion is attractive. The distribution function is partially accomplished by the very nature of solar radiation. Further, grains and grasses are grown in most states in quantities sufficient to warrant their consideration as a source of biomass material. Thus, the distribution function of energy production is largely accomplished by this existing dispersion. The photosynthetic process, in part, accomplishes the extraction function by collecting the sun's energy and storing it in plant matter available for use upon harvest. The location of a suitable conversion facility in close proximity to the biomass source, and convenient to the point of demand for the energy produced, completes the production cycle.

The prospect of placing millions of acres of marginal land into grass production as energy plantations is attractive as a painless solution to the energy problem. The use of residues from food and fiber production has a similar appeal.

Review of existing literature on the subject of terrestrial biomass production reveals that many aspects of the problem have been or are currently being addressed. Alich[1/] has developed a national inventory of residue from food and fiber agricultural crops; it excludes hays, grasses and forages. Lipinsky[2/] is investigating the conversion of biomass from sucrose production, and Inman[3/] is addressing silvicultural energy plantations. Many other papers and reports limit their scope to a few selected plant species or a unique growing condition. None have addressed, on a national basis, the potential for biomass production from grain and grass species with conversion to energy as a goal.

Thus, this study seeks to fill the gap in knowledge concerning terrestrial production of biomass material by developing a national inventory on a county-by-county basis of the potential for the production of biomass from grains and grass for conversion to fuel.

B. Objectives and Scope

The purpose of this project is to provide information to the U.S. Energy Research and Development Administration relative to the production of biomass from grain and grass species, which can be used as an aid in establishing research and development priorities in its fuels from biomass program.

The specific objectives of the project are as follows:

- To determine on a geographic basis the current U.S. production capability for biomass grown from grain and grass crops.

- To determine on a geographic basis the potential U.S. production capability for biomass from grain and grass species under several hypothetical scenarios, including the use of marginal lands, the use of underexploited plant species, or the use of modified cultural practices.

- To perform a preliminary screening of conversion processes to assess their suitability for the conversion of biomass from grains and grasses to energy products.

- To perform preliminary technical and economic feasibility analyses to select on a geographic basis those plant species and conversion process combinations which warrant further detailed investigation.

The scope of this project includes the members of the grass family (Gramineae) including the many species of sod crops which provide cured forage or pasturage for farm animals and the great food crops of wheat, rice, corn, millet, barley, oats, etc. The members of the legume family (Leguminosae)--the clovers, lespedezeas, alfalfas, and many others, are included within the scope of grains and grasses. Also included for consideration of their residue, or possible use as whole plant biomass, are those current agricultural food and fiber crops which occur regionally in sufficient quantity to be important sources of biomass.

Excluded from consideration in this study are the sugar crops of sugar cane, sugar beets, and sweet sorghums, and also biomass from silviculture, biomass from aquiculture, and animal agricultural wastes.

Conversion processes will be examined only to the extent necessary to determine their suitability for use with biomass from grain and grass sources, and the quantity and quality of biomass feedstock required. Technical and economic feasibility analyses will be preliminary in nature.

C. Study Approach

Grasses and grains which come under the purview of this program are comprised of a tremendous variety of grain-producing crops and forage and fiber crops. Also included in the list of potential plant varieties and species are several plants which have been under study for special purposes such as production of special oils, waxes, and fibers, typified by kenaf (fiber), crotalaria, guayule, and jojoba (oils and waxes). The range of potential plants also includes varieties which normally (or usually) are considered to be weeds, e.g., the sunflower. A large number of grasses fall within the general category of range or pasture grasses. Most of these are native grasses which have become adapted to the natural conditions of the areas in which they grow best. Others are adapted species which have been introduced to various regions of the country and have become important to the range/pasture economies of the regions.

An analysis of biomass production centered on grasses and grains must focus on the basic productive capabilities of various regions of the United States. The productive capabilities are a function of properties of the inherent land resource: soil type and depth, topography, permeability and retentivity to water; and climate: temperature regimes, precipitation, both quantity and seasonal variations, and sunlight. Native fertility is an important factor, together with augmentation of fertility through chemical fertilizers and other sources of nutrient elements, and the use of cultural practices which enhance nutrient availability. The above factors must be related to plant varieties of species so that the basic production capability can be optimized in the types of plants and cultural practices which will yield a maximum (or a sustained optimum) biomass output. It is possible that this optimum may be achievable without substantial deviation from the present agricultural land use. However, it is much more likely that a significantly different array of plants and cultural practices will prove to be optimum. The overall objective of this program, therefore, is to sytematically analyze various options and thus to determine what might constitute preferred uses of the basic production capability. For a first cut analysis, the evaluations should be conducted without the assumption of significant constraints, e.g., the inevitable conflict between use of available land for food crops versus use for energy. If this approach is taken, one should have available for further consideration, clearly defined land use options which can be weighed in terms of overall societal needs and objectives.

MRI's overall approach consists of the following:

1. A summation of the current situation with regard to biomass production from grasses and grains, with the following constraint: that only the residues remaining from food and fiber crop production are available for energy utilization.

2. A summation of the current situation with one constraint lifted. It will be assumed that grasses and forages utilized entirely or in part for livestock production will be diverted to biomass/energy use.

3. Analyses of plant varieties and species, taken from current knowledge of adapted species, which are suitable for growth in various regions of the country, and which are selected for maximum biomass production utilizing the whole plant.

4. Analyses of land availability, with emphasis on marginal land, accompanied by an analysis of suitability for growth of varieties and species identified in (3) above.

5. Delineation of cultural practices which are required for production of crops identified in (4) above, again emphasizing marginal land use. This analysis will include assessment of the fraction of total biomass yield which must be retained on the land to insure continuing productivity (this analysis will be performed for crop residue utilization also--Item (1)).

6. Preliminary analysis of economic factors, i.e., costs of production, processing, storage and transportation.

7. Summation and evaluation of biomass production which utilizes all of the available land resource and optimum plant varieties and species. This summation and evaluation will be subcategorized insofar as possible to illustrate such things as the potential of marginal land use, the potential for utilization of land currently devoted primarily to grass/livestock production, and the potential for growth of underexploited plants such as kenaf and bamboo.

The above activities will be augmented by a number of supporting studies which have the objective of integrating biomass production with biomass conversion. These include the following:

1. Documentation of the composition of plant biomass: elemental analysis; structural features such as oils, waxes, starches, cellulosic structure; moisture; ash, minerals; sulfur and nitrogen.

2. Documentation of energy content in calories/gm or other suitable units.

3. Derivation of quantities of biomass constituents available for specific energy use, e.g., alcohols.

4. Preliminary/conceptualized analysis of biomass conversion facilities in terms of economic sizes, specific energy outputs, and input requirements.

5. Preliminary/conceptual analysis of biomass production complexes conducted relative to optimum conversion plants. This analysis will have a strong economic/cost undertone. We expect that the analysis will be preliminary and conceptual in nature, however.

We have given considerable thought to the possibility of describing and analyzing plant species and varieties which are optimized for biomass production. Preliminary discussions with plant specialists generally indicate that while the genetic building blocks are known, the scientific community is not ready to propose modified species--this would appear to be a matter for research. On the other hand, there appears to be a substantial body of information about basic production capabilities as a function of plant species and environmental factors. For example, some information is available about sorghums which will significantly out-produce native grasses. In addition, it has been suggested that techniques such as relocating a long-season grain species, e.g., corn, to a region with a shorter growing season that will increase biomass yields at the expense of grain yields. We expect to pursue such avenues in a continuing search for plant varieties and species which will give greater biomass yields than the varieties and species which are currently in production.

The tasks which comprise this study, and the planned schedule for their completion are shown in Figure 1, Study Schedule. It should be noted that the initial tasks of this project consist of literature search and data collection activity to develop an information base for the study. These tasks will be completed prior to the next scheduled quarterly report, at which time more substantive results can be presented.

The planned content of the final report which will result from this study is described in outline form in Appendix 1.

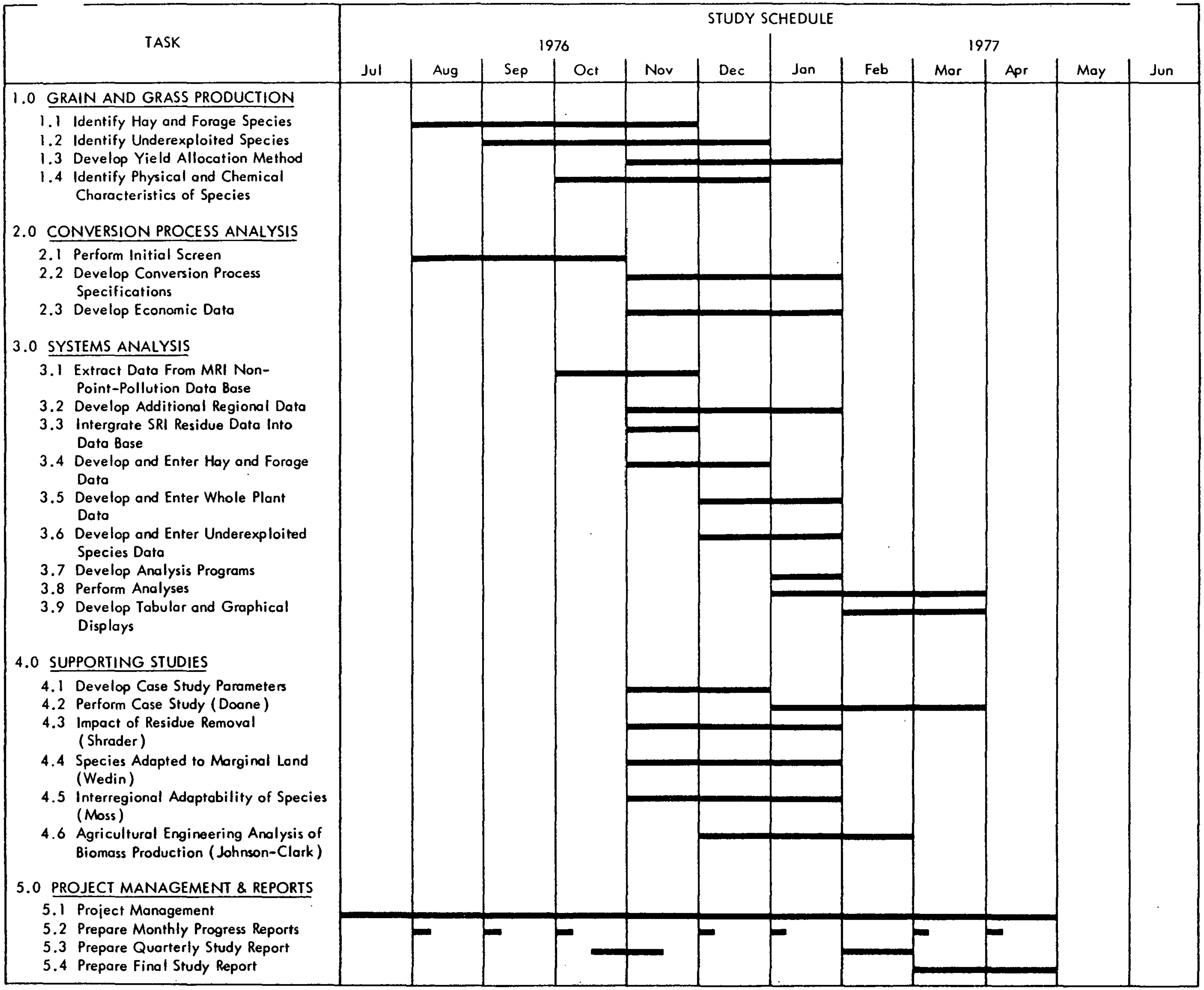

Figure 1 - Study Schedule

II. PROGRESS TO DATE

A. Summary of Progress

Progress to date has concentrated on the assembly of the data necessary for performance of the analysis portions of the study. The work is proceeding as expected, and it appears that, barring unforeseen difficulties, sufficient data to meet the objectives of this study will be available.

1. Grain and grass production data: Data concerning the production of grain and grass species are being assembled in four major categories as follows:

a. Current agricultural food and fiber crop residues: These data are being obtained from Stanford Research Institute from their NSF/ERDA study entitled, "An Evaluation of the Use of Agricultural Residues as an Energy Feedstock."

b. Current agricultural forage crops: Information on hays and forages are being obtained from a variety of sources. These species are not included in the SRI data base since, in most cases, the entire plant is utilized and little or no residue is available. However, for the purpose of this study, forage crops will be considered as a potential source of biomass material.

Forage crops include those members of the grass family (Gramineae), particularly the many species of sod crops which provide the cured forage or pasturage for all types of farm animals. (The great food crops of this family, wheat, rice, corn, millet, barley, oats, etc., are addressed in this study under the category of food crop residues.) Also included in forage crops are the legume family (Leguminosae)--the clovers, lespedezas, alfalfas, and many others.

The problem of addressing the many hundreds of individual species of hays and forages is greatly simplified by the fact that species of interest to this study are those which are grown in sufficient quantity to be of economic interest and are reported in the literature. Hence, the species addressed under this category of current agricultural forage crops is reduced to a manageable size.

At this point in the study, an initial list of forage crop species and their general growing characteristics has been identified. Additionally, the availability of yield data for the major crop species has been determined. Preliminary tables describing major physical and chemical characteristics of these forage crops have been prepared; however, these tables must be further amplified to include characteristics of environmental concern, such as sulphur and silicon content.

c. Range grasses--potential whole plant biomass: The collection of data concerning range grasses of potential interest to this study is a more difficult task than the hays and forage crops, particularly if one hopes to attain a high degree of precision regarding yield data. Soil and climate in the various regions of the United States have large influence on both native grasses and introduced grasses that can be grown in a given county. Species and general growing characteristics are readily available; however, yield data of the type useful to this study are not formally reported. Estimates of range grass production have been obtained from the U.S. Department of Agricultural personnel at the Southern Great Plains Research Station. It is anticipated that similar information will become available from other regional USDA research stations.

d. Underexploited species: Included in this category are plant species which are grown within the continental United States, but which are not exploited to any great extent for commercial use. Weeds fall into this category, as do other species not currently grown commercially but which have high biomass yield potential such as kenaf. Plant species indigenous to semi-arid regions such as guayule, and the jojoba plant will also be included. Certain agricultural food crops may also be included in this category if they appear to have the potential for high biomass yield under intensive cultural practices. One such species is artichoke. The many species of bamboo which can be grown in the United States on marginal land, also apappear to have promise. One member of the bamboo family, giant reed (Arundo Donax, Linn), has yielded 12 ft high cuttings annually for 35 years from a single planting in marginal soil.

Yield data on these underexploited species are, as expected, less available than on commercial crop species. A single planting may be the basis for yield estimates, lacking geographic and temporal distributions. We are aware of the problems associated with developing projections based on inadequate sample size, and will exercise caution in entering these figures into the data base. As a minimum, yields extrapolated from limited observations will be flagged.

2. Conversion processes assessment: An assessment of the conversion processes which are available to convert grains and grasses to energy products has been initiated. Preliminary results from this effort are included in this report.

The state-of-the-art survey of conversion processes for possible use with biomass from grains and grasses investigated coal conversion technologies, solid waste conversion technologies and biodegradation conversion technologies. The results are presented in a later section describing the current status of a large number of these processes. Selected processes are discussed further in the text of the report.

a. Coal conversion processes: The most attractive coal conversion processes for use in converting grains and grasses to energy products appear to be the following:

Solid, Liquid and Gaseous Products	Gasification
• Coalcon Hydrocarbonization	• Koppers-Totzek
• Fischer-Tropsch Synthesis	• Lurgi Pressure Gasification
• Garrett's Coal Pyrolysis	• Wallman-Galusha
• Solvent Refined Coal	• Winkler

b. Solid waste conversion processes: Solid waste conversion technologies were reviewed for potential use with grain and grass biomass as a feedstock. While direct combustion or incineration is certainly a viable alternative, these processes were not reviewed at this time. The most promising pyrolysis processes for converting grains and grasses to energy products appear to be the following:

Garrett
Union Carbide
Monsanto "Landguard"
Devco
Rust Engineering

c. Biological conversion processes: Biological conversion technology was also reviewed. The primary utilization of these biodegradation conversion processes to date has been directed toward sewage and municipal refuse. The Pfeffer-Dynatech anaerobic digestion system is probably as well developed as any process of this type.

The work to date in the survey of conversion processes represents the initial step in the selection of type conversion processes used in the analysis portion of this study with plant specification detail limited to that necessary to determine the interface between biomass material and the conversion process. For the selected process(es), feedstock requirements such as physical and chemical characteristics, and annual throughput requirements will be determined. This information will provide a basis for estimates of total acreage of biomass production which will be required to support the conversion facility in the various regions of the United States.

3. Data management system: Work has also been initiated in the development of a data management system to be used in the analysis portion of this study. An existing data base and data management system developed by MRI in an earlier study of non-point pollution for the Environmental Protection Agency has been used as the basis. This existing system contains a large quantity and variety of data on agriculture production on a county basis. Additionally, soil classifications, rainfall, topographic information, temperature and humidity data, conservation practices, acreages of crops, etc., are all contained in the data base of this existing system on a county basis.

The data on agricultural food and fiber crop residues will be obtained from Stanford Research Institute's study on that subject in machine readable format compatible with this existing data base. The use of the county as a basic building block will facilitate the aggregation of analysis results into appropriate regions of interest.

The original data base of the EPA study contained some 5 million data points, many of which are excess to the needs of this study. We are in the process of developing a reduced data base screened from the original for use in the analysis portion of this study.

Each of the three major areas of activity mentioned above, biomass production, conversion processes, and data management are discussed in the sections which follow.

B. Production of Biomass from Grasses and Grains

1. Factors governing biomass productivity: The key to maximum biomass production is selection of species of cereal grains, grasses or legumes which have the most desirable characteristics for maximum cellulosic production. Species can be selected either from currently exploited species of plants, or from underexploited species which are indicated to be adapted to a specific geographic location. Environmental requirements of the native vegetation are a reliable indicator of the agriculture possibilities of a region. The natural plant cover indicates the crop producing capabilities of the land since it is a measure of conditions favorable or unfavorable to plant development.

Under identical precipitation and other climatic conditions, native vegetation may vary greatly. These differences are primarily due to soil types. In the prairie regions of the Great Plains which have extensive areas of hard, compacted, very fine silt loam, the growth of the more shallow-rooted short or mid-grasses is favored. Where the soil contains mixtures of sand and is termed a sandy loam, runoff is greatly reduced and the water penetrates the soil for a depth of 3 to 4 ft. This type of soil favors species of grasses which are taller and more deeply rooted than the short grasses. When the soil becomes so sandy that there is no runoff, as all of the rainfall is absorbed, a bunch grass type of vegetation prevails.

The short grass type of native vegetative growth indicates that the soil has much runoff, low-water penetration and a shorter growing season due to limited water storage ability. Such land is not well adapted to late developing, deeply rooted crops such as corn, while early maturing crops such as winter wheat will give a good yield on this soil type. Because of the high fertility of hard soils, crops make a rank growth early in the season when rainfall is plentiful, and are poorly adapted to withstand drought.

In the sandy loam soils, almost all of the rainfall penetrates, and surface evaporation is greatly reduced. Fertility is still sufficiently high that crops grown on these soils during years of favorable rainfall are almost as good as those on the hard lands. During dry years much better crops are produced, because the moisture is distributed to a considerable depth, and when drought threatens, plants are able to draw on the reserves found in the deeper layers of the soil.

Soils that are sandy in texture allow penetration of practically all of the water that falls. The native plants indicate a long season for growth; the roots of crops spread widely and deeply, and plants rarely wilt because of drought. Crop growth is much less luxuriant on this land due to decreased fertility. Therefore, the retardation in growth is a factor in conserving the water supply.

Crop failures occur most frequently on the hard or silt-loam soils and least often on the sandy textured soils. However, during favorable years, yields are highest on the former and lowest on the latter. The sandy-loam soils represent a safe intermediate condition in that during favorable years crops are almost as good as on the silt-loam soils, and during dry years a fair crop can be produced.

The above generalizations will hold true for areas of low annual rainfall, but as the amount of annual rainfall increases, the subsoils of even the hard or silt-loam lands may become moist and favor the growth of the late developing, deep rooted plants.

Therefore, the selection of species and varieties of plants is concerned with matching plants with their environment. The selection process is a matter of balancing the factors within the plant such as photosynthetic efficiency of the species, photorespiration, CO_2 compensation point, leaf area and leaf arrangement with environmental factors such as quality and intensity of solar radiation, availability of CO_2, photoperiod, temperature, soil type, and annual rainfall.

Some species have special features which are invaluable toward attaining maximum biomass production. Those species which are particularly adapted to tropical or subtropical regions generally have a C_4 or CAM metabolic pathway, which allows these plants to maximize growth during periods of higher temperature and long day length. These C_4 plants also are able to use lower levels of CO_2 than the plants adapted to more temperate regions, which generally have the C_3 or Calvin metabolic pathway. Plants adapted to the warmer areas which have the C_4 metabolic pathway are corn, sorghums, sunflower, kenaf, corn grass, selected bamboos, and forage grasses such as hybrid sorghum, sudan grass and napier grass. These plants are able to maximize biomass yields, by more fully utilizing periods of high temperature and long days.

Native vegetation may be adapted grasses which are quite low in yields of biomass. For example, yields of buffalo grass in western Oklahoma, are 800 to 1,200 lb/acre under dry land conditions, whereas, sorghums (three different varieties) over a period of 34 years under dry land conditions yielded about 3 tons of biomass per acre in experimental plots. This result indicates that yields of biomass may be substantially improved, relative to yields of native grasses, by selection of species which can better utilize the resources of an area. This conclusion would appear to apply particularly to the areas of the country with relatively low rainfall.

Yields of these grasses, if harvested for biomass, must be developed out of statistics which are presently being examined. The general range of potential biomass yields varies from less than 0.5 tons per acre in low rainfall areas to several tons per acre in higher rainfall/long growing season areas. Yields are also sensitive to management and cultural practices, i.e., to establishment of healthy stands of specific single or mixed species, weed control, fertilization, and to the type of land committed to grass production. As a general rule, the grasses are grown on land which is somewhat less than optimum for cultivated crops, and yield data reflect this factor.

A significant factor in an analysis of the grasses in terms of biomass production is the large acreages which, in current agricultural practice, are suitable for and committed to, grass production. The permanent acreage in grass is supplemented by additional acreages which are suitable for cultivated crops, but which are being held in reserve or are involved in shifting conservation programs and crop rotations. The grasses provide an essentially permanent ground cover and root mass, with minimal cost for grass stand maintenance. The acreage in grass can thus be kept in continuous production without serious problems from water and wind erosion. Class V and higher lands are thus principally committed to the grass and livestock economy, as well as some of the land classes suited to cultivated crop production.

The acreage in the aggregate is a substantial potential resource for biomass production. Utilization of the capability may be unattractive in economic terms for minimally productive areas, and may require specially adapted cultural practices and plant varieties for the more productive areas. It is perhaps self-evident that special attention should be given to supplanting the native grasses with other plant species in order to more effectively utilize the resource; one such possibility consists of the use of perennial sorghums (sudan grasses) on lands which are relatively poor producers with native grasses.

A description of the species of grasses, cereal grains, and legumes which have been selected to be grown because they have exhibited desirable characteristics as a food or fiber for human or animal consumption is presented in Appendix 2.

2. Underexploited plants: Underexploited plants is a term applied to plants which have not been extensively grown, plants for which no present market exists, or plants which are classified as weeds relative to current food and fiber production. They may be reasonably well known plant varieties or they may be species which have not been exploited because they do not compete favorably with the varieties and species which are grown for grain, forage, or fiber. They also may be obscure or experimental plants in the United States. The jojoba and guayule plants are among those experimental plants which have been studied in some depth for special applications. Kenaf is of interest as a fiber producer but has not yet prospered because of the firm position occupied by forestry products. Milkweed, cattail, and thistles exemplify weeds which could be grown for their biomass content. Sunflower, which is grown for seed production, is also a weed which has high biomass yield. The giant reed and bamboo are well known in other areas of the world, but have little commercial interest in the United States.

Information on a number of these underexploited plants is briefly summarized below.

a. Kenaf (Hibiscus cannabinis L):[17,23,26] Kenaf has been extensively studied in the United States, primarily as a fiber producer. It thrives best under conditions of high temperature and soil moisture, i.e., the South and Southeast. Under favorable conditions, yields of dry matter are routinely 10 tons per acre or better, with 20 tons being observed under ideal conditions. While cooler climates are less favorable, predicted yields of dry matter are 5 tons per acre as far north as Kansas/Nebraska, and 2.5 tons per acre in Northernmost parts of the country. Kenaf is relatively immune to disease and insects, although it is highly susceptible to root-knot nematodes. Response to fertilization varies with the soil; in certain soils added fertilizer has given no significant increase in yield.

Kenaf is an annual and can be propagated from seeds with conventional drilling machinery. Stand heights vary with planting thickness, rainfall, and other factors, and can be 20 ft high. Harvesting equipment of the types used for sorghums and corn would likely be employed if kenaf were harvested for biomass.

Kenaf will not tolerate much standing water, and production would thus be restricted to regions with relatively good drainage characteristics. One concludes that Kenaf is a prime candidate for biomass production in the Southern moderate-to-high rainfall areas of the United States. In addition, Kenaf has potential for utilization in Central to Northern parts of the country.

b. Giant Reed (Arundo Donax, Linn):[27/] The USDA Southern Great Plains Experiment Station maintains a small plot of this plant. The plot has been planted in Giant Reed for about 30 years, with the stand maintaining itself without attention (no irrigation or fertilization) other than fall harvest. The canes grow as high as 15-18 ft, and can be harvested with conventional mowing equipment. The green yeild, on a per acre basis, at the end of the 1976 season is 72.6 tons per acre, which translates to a dry yield of about 20 tons per acre. This is a very good yield in a low rainfall area (16 in. per year). The climatic region in which this plant is known to be hardy covers most the Southern half of the United States (the 180-day frost-free region). The dense stands remain upright, even when dry, a factor which is of importance in harvesting. Conventional harvesting and processing equipment are judged to be satisfactory without modification.

The bamboos are largely underexploited in the United States. Research on bamboo in this country has been directed at the kraft pulp industry and has shown that per acre yields are better than yields from comparable slash pine yields. Certain of the bamboos are noted for their rank and rapid growth and aggressive growth habit. Especially worthy of note is the report that stands of bamboo are particularly effective in stabilizing steep slopes. The natural distribution of bamboos in the Western Hemisphere extends from the Southern part of the United States southward to Argentina and Chile and from sea level to 12,000 ft in the tropics. Certain varieties are reported to thrive from Florida to New York, and in corresponding climates westward.

The ARS, USDA Wind Erosion Laboratory in Big Springs, Texas has also investigated giant reed. The primary interest is wind erosion control, and some study has been conducted of water erosion in gullies. At Big Springs, the giant reed was found to be quite hardy, with extensive root systems. Propogation was accomplished by planting rhizomes in lister furrows. The root system develops to the extent that plowing and chiseling are very difficult, and established stands are difficult to kill. Herbicides were effective, however. Yields from rows were estimated at 10 tons per acre, with smaller yeilds expected for continuous stands.

The growth habit is adapted to sloping land with water being the principal determinant. It is to be expected that established stands could be resistant to water erosion, and that available water supplies would be conserved for plant growth, factors of importance relative to marginal land use.

Rhizomes spread at the rate of 10-15 cm per year and reach a diameter of 2-5 cm. The lateral spread of the root system in Big Springs was 8-10 meters. Experience at wind erosion laboratories in Kansas has shown that relatively shallow rhizomes are subject to winter-kill.

The giant reed has not been observed to be affected by disease and insects.

c. Hemp (Cannabis sativa):[22/] Hemp has been grown for fiber in the United States primarily in the North Central states. U.S. production has, for many years, been barely competitive with foreign sources of fiber and production is very limited. It requires rich silt or clay loam soils. Marshes have yielded rank growths, but the quality for fiber was low. Yield data presently on hand indicates that hemp, as it is cultured for fiber, will not be a serious competitor to other plants for biomass production (2 to 2-1/2 tons per acre of air dry stalks on prime land). However, the indication of high yields of low quality fiber on mulch or peat soils is of potential interest.

d. Jute (Corchorus capsularis, white jute): Corchorus olitorius (tossa) requires hot steaming climates and rich alluvial soils. It is grown primarily in Pakistan and India. White jute is adapted to very wet (flooded) soils, tossa to higher ground and drained soils. Yields of total plant biomass are not available (fiber yields in Pakistan average 1,200 lb/acre). Jute could be considered only for very limited areas of the United States, namely, semi-tropical wetlands.

e. Guayule (Parthenium argentatum - Gray): Guayule is a shrubby plant which has been extensively investigated for rubber production. The plant is desert-oriented, being acclimated to the Great Bend area of Texas and west. Rainfall requirements for reasonable nonirrigated production are 15-16 in. per year. Yields vary with maturity of the plant and with climatic and other conditions. With a 4-yr cycle, "rubber" yields are of the order of 2,000 lb per acre (500 lb/acre/year). This yield translates into a total biomass yield of about 1-1/2 tons/acre/year (estimated from sparse data).

The plants, including roots, are sacrificed at harvest after a several-year growth period.

Guayule is a possible candidate for growth in semi-arid conditions under dry land conditions, where its ability to utilize available moisture resources is an important factor. The fact that it has been investigated in some detail is another important consideration. It has been suggested that the range of hardiness can be extended to more northern climates by hybridization, and that yields can also be increased significantly. The hybridization process should be relatively simple. These considerations reinforce the tentative conclusion that guayule may deserve serious consideration in this program.

Worthy of mention also is the fact that an overall production system appears to have certain characteristics which sould translate into a cost-effective scenario with harvesting being considerably less seasonal than is the case with annual crops. Specifically, a guayule-based production system with multiple stands might operate on a 4 to 5 year cycle, with relatively large per harvest yields (8-10 tons/acre).

f. Jojoba (Simmondsia Chinensis):[20] The jojoba plant is another desert-oriented plant. It has been studied as a producer of oils. The plant is a long-lived perennial which requires several years to come into production. Annual yields of the beans are indicated to be in the 1/4 to 3/4 ton/acre range, which tentatively places it in the marginal category for biomass production.

g. Weeds: A number of plants can be classified as underexploited, for purposes of this program, because they may have relatively little present commercial significance and may, in fact, be weeds. Obviously, the number of plants which fit this classification is quite large. Some which have been suggested for consideration are briefly described below.

The sunflower is widely adopted throughout the country. It usually is considered to be a weed, but significant acreages are under cultivation for seed production. It appears to merit consideration, although yield figures have not yet been developed. It differs from the majority of the so-called underexploited plants in that it is adapted to Northern climes.

The hollyhock (a plant not normally considered a weed) has been suggested as a possible candidate. It, too, is adapted to Northern climes, including low rainfall areas such as Montana. Yield data have not yet been developed.

Cattails have been suggested as a candidate for growth in peat/marshy areas, including the Northern peatlands. Very lush growth has been observed in limited studies.

Varieties of thistle, e.g., the Canada thistle and the bull thistle, are well known for their hardiness, persistence, and rank growth. American agriculture has been devoted to repression os these weed species, and specific information on yields may not be readily available. Furthermore, cultural practices needed for production have not been established.

Many other weedy plants could be added to this abbreviated list. Because of an anticipated general dearth of information on cultural practices, yields, compositions, etc., it is not expected that this general area will be given more than a cursory analysis which will suffice to indicate whether such plants should be considered in greater depth. Special situations, such as cattails grown in peat bogs, will deserve a more thorough analysis. A very legitimate concern with weeds is the possibility that cultivation of crop weeds will aggrevate an already serious problem with weed control in cultivated croplands. The risks should be weighed very carefully.

C. State of the Art of Conversion Processes for Grains and Grasses

1. Introduction: The purpose of the following analysis is to provide an assessment of conversion processes which are available to convert grains and grasses to energy products.* The production of grains and grasses as a source of energy must be coupled with a realistic and workable method of converting the biomass to gas, oil, char, alcohol, etc. With this goal as a guide, the following review procedure was designed to identify the most promising conversion processes. Because a limited amount of work has been done in the general area of converting biomass to energy products, a review was made of the following related technologies:

- Coal conversion technology
- Solid waste conversion technology
- Biodegradation conversion technology

Each of the related conversion technologies was reviewed with the intent of determining which processes were experimentally proven and, therefore, a potential candidate for the current study. This task was fairly well defined in the case of both coal and solid waste conversion processes, but was more subjective for biodegradation processes due to the somewhat limited commercial verification of various schemes.

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* The assessment of conversion technologies is only a state-of-the-art review, or initial screen, and does not constitute a definitive selection process for converting grains and grasses to energy processes. However, should the analysis of the production of biomass prove to be promising, then a more definitive analysis of the candidate conversion processes will be required to support future detailed technical and economic systems studies.

Following the initial screening process, detailed flow diagrams and primary operating parameters will be generated for each candidate process. The physical and chemical characteristics of the species of grains and grasses will need to be compared against the feedstocks normally processed in each conversion process. Acceptance criteria will be developed for each conversion process (e.g., some processes may not be capable of handling materials which cake or agglomerate, while other processes may operate inefficiently using material with a high ash content). Finally, each candidate conversion process will be compared against the acceptance criteria and the physical and chemical characteristics of the species of grains and grasses. Then, it will be possible to determine which species can be treated by the various conversion processes.

The major references used in this survey are listed at the end of this report; it is not an all-inclusive list.

2. Coal conversion technology: The various coal conversion processes were subdivided into three general categories:

- Coal conversion processes for the production of solid, liquid, and gaseous products.
- High Btu coal gasification processes.
- Low and medium Btu coal gasification processes.

Each conversion process within these categories is identified by process name, process developer, and current status (based on demonstrated capacity).

The stage of development of each process is indicated by commercial, demonstration, pilot unit, process design unit, or bench scale unit. Table I contains a definition of each of these classifications. Obviously the classifications will change as ongoing work with the various processes continues.

TABLE I

CONVERSION PROCESS CLASSIFICATION SCHEME

Plant Description	Symbol	Plant Size (ton/day)
Commercial plant	C	Full size
Demonstration plant	D	1/3 full size
Pilot plant	P	10 to 1,000
Process design unit	PDU	1/4 to 10
Bench scale unit	B	Small

Not every coal conversion process that was reviewed is listed in the accompanying tables. Reasons for not including some processes were:

- Early stage of laboratory development.
- Insufficient information available on process details.
- Processes that have been discontinued.
- Unproven technology.
- Process not applicable to biomass conversion (e.g., in situ gasification).

Tables II to IV contain the results of the review of coal conversion processes. Tables II and III are complete, while the processes presented in Table IV are intended to be treated as those processes which are only low/medium Btu gas processes. All of the processes listed in Table III are also low/medium Btu gas processes.

Coal gasification processes are generally classified as high Btu gasification processes or as low Btu gasification processes depending upon the Btu content of the product gas. Normally, high Btu process gas has a heating value of 900 to 1,000 Btu/scf, while low Btu gas characteristically has a heating value of 100 to 200 Btu/scf. Gas having a heating value between these ranges is termed medium Btu gas.

High and low Btu coal gasification processes utilize very similar processing through the gasification and gas clean-up stages. Low Btu gasification systems do not employ CO shift and methanation steps used in high Btu processes. The low Btu product gas produced using oxygen blown gasifiers is essentially the same gas that is catalytically upgraded to pipeline quality gas in high Btu gasification processes. Essentially, the difference between high Btu processes and low/medium Btu processes is related to whether oxygen or air is used in the process. The diluent effect of the nitrogen in the air lowers the heating value of the product gas.

The most attractive coal conversion processes for use in converting grains and grasses to energy products appear to be the following:

Solid, Liquid and Gaseous Products	Gasification
• Coalcon Hydrocarbonization	• Koppers-Totzek
• Fischer-Tropsch Synthesis	• Lurgi Pressure Gasification
• Garrett's Coal Pyrolysis*	• Wellman-Galusha
• Solvent Refined Coal	• Winkler

* Process currently being developed by Occidental Petroleum Corporation.

TABLE II

COAL CONVERSION PROCESSES FOR THE PRODUCTION OF SOLID, LIQUID, AND GASEOUS PRODUCTS

Process Name	Process Developer	Current Status	Demonstrated Capacity (ton/day)	Comments
Bergius	F. Bergius (Germany)	C	1,000	Low efficiency, high pressure process.
Catalytic Coal Liquefaction (CCL)	Gulf Research and Development Co.	PDU	1	Can utilize high ash coals.
Clean-Coke Process	U.S. Steel Corp.	PDU	1/4	
*Coalcon Hydrocarbonization	Union Carbide Corp. and Chemical Construction Corp.	P	300	This is a multi-product process (methane, liquid fuels, chemicals).
COED	FMC Corp.	P	36	Process could be made commercial in a short time span. This is a multi-product process (char, oil, gas, synthetic crude oil). This process is currently discontinued.
COGAS	Cogas Development Co.	P	50	This is a multi-product process (char, oil, gas, synthetic oil).
Consol Synthetic Fuel (CSF)	Consolidation Coal Co.	P	70	Some problems with hydrogen consumption and catalyst life.
Exxon Liquefaction	Exxon Corp.	PDU	1	
*Fischer-Tropsch Synthesis	Fischer and Tropsch (Germany), M. W. Kellogg Co., Arge-Arbeit Gemeinschaft Lurgi and Ruhrchemie	C	6,600	This process has been operated continuously since 1957 at Sasolburg, South Africa. It can be used with various gasification processes.
*Garrett's Coal Pyrolysis	Garrett Research and Development Co.	PDU	3.6	Process currently being developed by Occidental Petroleum Corp.
*H-COAL	Hydrocarbon Research Inc.	PDU	3	This is a multi-product process (oil, gas, chemicals).
Lurgi-Ruhrgas	Lurgi GmbH	C	1,600	Can utilize high ash coals.
Solvent Extraction-U.O.P.	Universal Oil Products Co.	PDU	--	
*Solvent Refined Coal - PAMCO	The Pittsburgh and Midway Coal Mining Co.	P	50	Most promising of the SRC processes. The product is a solid containing low ash and low sulfur.
SYNTHOIL	U.S. Bureau of Mines	PDU	1/2 (10 ton/day unit just starting)	
TOSCOAL	The Oil Shale Corp.	P	25	Adaption of TOSCO-II oil shale conversion process.

* Most promising processes.

TABLE III

HIGH BTU COAL GASIFICATION PROCESSES

Process Name	Process Developer	Current Status	Demonstrated Capacity (ton/day)	Comments
Agglomerating Ash	Battelle Memorial Institute	P	25	Can utilize highly caking coals.
BI-GAS	Bituminous Coal Research Inc.	P	120	
CO_2 ACCEPTOR	Consolidation Coal Co.	P	40	Sulfur removal takes place in the gasifier. This process can be operated without oxygen or hydrogen being supplied externally.
Exxon Gasification	Esso Research and Development Co.	PDU	1/2	
Garrett's Coal Gasification	Garrett Research and Development Co., Island Creek Coal Co.	PDU	3.6	Process currently being developed by Occidental Petroleum Corp.
Hydrane	U.S. Bureau of Mines	B	1/4	Can utilize highly caking coals. Shows promise because of the high thermal efficiency.
HYGAS	Institute of Gas Technology	P	75	Can be commercialized in a short time span.
*Koppers-Totzek	Heinrich Koppers GmbH (Germany)	C	850 (per unit gasifier)	Environmentally attractive because the volume of tars and phenolics (oils) is reduced.
*Lurgi Pressure Gasification	Lurgi Gesellschaft fur Warme-und Chemotechnik mbH	C	1,000 (per unit gasifier)	Most proven technology for converting coal to gas.
Synthane	U.S. Bureau of Mines	P	70	
*Wellman-Galusha	McDowell-Wellman and Wellman-Galusha	C	60 (per unit gasifier	Commercially available process.
*Winkler	Davy Powergas, Inc.	C	1,000	Commercially available process. Can be used with coal having a high ash content.

* Most promising processes.

TABLE IV

LOW AND MEDIUM BTU COAL GASIFICATION PROCESSES

Process Name	Process Developer	Current Status	Demonstrated Capacity (ton/day)	Comments
Agglomerating Ash	Union Carbide Corp., Battelle Memorial Institute	P	25	Can use highly caking coals. Product is free of entrained particulates.
Babcock & Wilcox - DuPont	U.S. Bureau of Mines	C	400	
Combined Cycle B&W	Babcock & Wilcox Co.	P	60	Product gas is used in a conventional gas turbine.
Combustion Engineering Entrained Fuel Process	Combustion Engineering, Inc.	P	180	
Pittsburg-Midway Process	The Pittsburg and Midway Coal Mining Co.	D	1,200	
Stirred Fixed Bed	U.S. Bureau of Mines	P	20	Stirrer breaks up caked coke.
U-GAS	The Institute of Gas Technology	P	50	
Westinghouse Low-Btu Process	Westinghouse Electric Corp.	P	15	Can utilize highly caking coals.

3. <u>Solid waste conversion technology</u>: The solid waste conversion technology reviewed consisted of incineration, composting, and pyrolysis processes. Although incineration of biomass is certainly a viable alternative, a review of incineration processes is not warranted at this time. The co-firing of coal (and oil) with municipal wastes in utility boilers has established operating experience which is largely applicable to the incineration of biomass. This experience is sufficient to include incineration as a candidate conversion process for biomass. If a more detailed analysis of conversion processes is required, the following incineration processes will be covered:

- Batch feed systems
- Continuous feed systems

  1. Grate burning
  2. Suspension burning

     a. Gas stream
     b. Gas stream plus fluidized bed

Composting does not appear to be applicable to the conversion of grains and grasses to energy products.

Pyrolysis is a complex process of simultaneous and consecutive chemical reactions. While a complete description of the specific reaction types occurring has not been determined, it is generally believed that reactions such as cross-linking, isomerization, de-oxygenation, de-nitrogenation, etc., do occur. The reactive portion of the solid waste is composed primarily of cellulosic material. The decomposition of the cellulosic material starts to occur at about 360°F, producing a mixture of solids, liquid, and gas, the proportions and composition depending on reactor conditions and environment.

Pyrolysis reactors have been designed to handle a variety of refuse feedstock conditions and therefore may be adapted to agricultural biomass. Conceptually, a system may be designed to handle either a raw feed or a preprocessed feed. The preprocessing decisions are dictated by characteristics of the feedstock, but will also have a direct effect on required reactor equipment such as feed and discharge devices, etc. In general, a dried, finely shredded feedstock is most desirable from a reaction viewpoint.

Several basic reactor types have been used for pyrolysis reactions. The most common can be classified as follows: (1) shaft, (2) rotary kiln, and (3) fluidized bed.

Shaft reactors (horizontal and vertical) are conceptually the simplest and lowest in capital cost. In the vertical type, the feed material is fed into the top of the reactor and settles into the reactor under its own weight. Generated pyrolysis gases pass upward through the shaft and are removed from the top. Typical feed mechanisms include screw conveyors, rotary devices and rams.

The horizontal shaft type incorporates a feed conveyor system through the reactor housing. Feedstock is thus continuously pyrolyzed from the conveyor system. Feed and discharge problems are minimized but reliability of conveyors at elevated temperatures can be a problem. Both types of vessels are constructed of metal capable of withstanding high temperatures or are lined with a refractory material.

The rotary kiln is a rotating cylinder usually slightly inclined to the horizontal. Feed material is charged into one end of the kiln and progresses through the kiln by means of rotation and slope of the cylinder to the opposite end where it is discharged. The metal cylinder is normally lined with a refractory brick. The rotary kiln has mixing advantages over the shaft type reactor, but the sealing of the rotating cylinder from the stationary feed and discharge ports can be a problem.

The fluidized bed reactor consists of a bed of solid particles (e.g., sand) suspended by an upward flowing gas stream. For pyrolysis applications, the solid particles are heated and serve as the heat source for the pyrolysis reactions. A chemical reaction involving the solid particles may occur. The major advantage over other reactor types is improved heat transfer and temperature control. The primary drawbacks include erosion and carry over problems associated with the solid particles, gas velocity control and solids transfer and separation problems.

Table V lists 24 pyrolysis projects in progress or completed (1974). The status of each project is indicated. The most promising pyrolysis processes for use in converting grains and grasses to energy products appear to be the following (due primarily to their commercial status):

- Garrett
- Monsanto "Landgard"
- Union Carbide
- Devco
- Rust Engineering

4. Biological conversion technology: The biodegradation conversion technology reviewed included both methane production processes and biochemical processes. The primary utilization of these biodegradation conversion processes to date has been directed towards sewage and municipal refuse, and a limited amount of research has been done with various biomass species. Although fermentation of biomass is a viable alternative, the overall process is well known and a review of this conversion technology does not appear to be required at this time. The experience gained through many years of operating history with fermentation processes is sufficient to include fermentation as a candidate conversion process for biomass. If a more detailed analysis of conversion processes is required, the fermentation of biomass to produce alcohol will be included.

TABLE V

PYROLYSIS REACTOR CLASSIFICATIONS

	Heating Method		Product Distribution			Feed Conditions			Reactor Temperature	Status		
	Direct	Indirect	Solid (Btu/Lb)	Liquid (Btu/Lb)	Gas (Btu/Ft^3)	Raw	Size Reduction	Separation	°C	Research	Pilot Plant (TPD)	Commercial (TPD)
VERTICAL SHAFT												
Garrett		X	9,700	10,500	550		X	X	900		4	200
Battelle	X	X			170		X		1800		2	
Ga. Tech.	X		10,000	13,000	200		X		750		25	
URDC	X				150	X			2600		120	
Torrax	X				150	X			3000		75	
Union Carbide	X				300	X			3000		5	200
HORIZONTAL SHAFT												
Kemp		X	X	X	X		X		1100		5	
Barber-Colman		X			500		X	X	1200		1	
ROTARY KILN												
Monsanto	X		2,500		130		X		1800		35	1,000
Devco	X		X		X		X	X	1000		120	1,500
Rust Eng.		X			450				1250			260
Pan Am Res.		X					X		200	X		
FLUID. BED												
W. Virginia		X			450		X	X	1400	X		
A. D. Little		X			X		X	X		X		
Coors	X				150		X	X	1400		1	
OTHER												
Battelle		X							1800	X		
Hercules			X							X		
Bur. Mines		X			500		X	X	1800	X		
NYU		X							1700	X		
USC		X								X		
Anti Poll. Syst.										X		
Univ. Calif.		X					X			X		
Wallace-Atkins		X	3,000	16,000	500				1600	X		
Res. Sci.		X					X		1800		2	

The production of methane from solid waste is always the result of the anaerobic decomposition of the organic fraction of the solid waste. Since the methane bacteria require an oxygen deficient or reducing atmosphere, the methane production process requires an isolated air tight environment in which to ferment the feedstock material. The same is true for the treatment of grains and grasses.

The anaerobic decomposition of any complex organic substance is basically a two-stage process. The first stage consists of the breakdown of the complex organic materials by acid formation bacteria into organic acids with the production of CO_2. These organic acids in the second state are acted on by bacteria known as methane formers to produce CH_4 and CO_2. The methane producing bacteria consist of several different groups, with each group having the ability to ferment quite specific cellulosic material. Therefore, the bacterial mixture in a methane producing system should be selected specifically for the feedstock to be introduced into the system. The rate of bacteria production becomes important, as it is a function of retention time. For periods of 10 to 15 days of retention time, the rate of reduction is limited by methane fermentation. For systems where the retention time is longer than 15 days, the rate limiting aspect is then the hydrolysis of the organic solids.

Since the microorganisms in anaerobic decomposition attack the material from some point on the surface, the size of decomposable material is directly proportional to the decomposition. Therefore, the surface area per unit volume must be maximized, i.e., the material should be as finely ground as economically possible. This requirement will be important when the various species of grains and grasses are processed.

Since no extensive pilot plants have been constructed, no engineering or economic data exist on the use of methane digesters for the conversion of solid waste.* Again, the same is true of converting biomass to methane. Introductory pilot plant studies by Stanford University show that a large percentage of organic fraction is non-decomposable. Also, those parts of the waste which float on the slurry and resist agitational mixing do not decompose as readily as the same material would if submerged. (This was found to be a problem with corn stalks during one research effort.) Thus, the laboratory studies used to predict the volume of solids remaining seem to be too low when plant size is scaled up. The volume that would be processed at any one time for an economical production facility dictates that small scale plants be tested first. In the case of converting biomass to energy, these pilot plants should be located in regions where the specific biomass is produced.

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* This is not the case with sewage. Both the Mogden sewage plant in London, England and the Hyperion sewage plant in Los Angeles, California produce a fuel gas of intermediate heating value.

The most promising area of application is the processing of specialized types of organic waste such as animal manure or food wastes. Here the technology is readily applicable and the environmental regulations are making these applications necessary. Plants developed for processing these homogeneous organic waste products should provide the engineering data needed to determine areas where further research efforts are required.

The Pfeffer-Dynatech anaerobic digestion system is probably as well developed as any process of this type. Even though a working plant prototype system is not presently in existence, the system is well researched and is based on proven technology. The extent of this review process does not permit an analysis of the effect of using biomass in place of solid waste.

Biochemical processing by definition means that the characteristic chemical aspects of specific biological organisms are employed to convert organic material. The biological organisms will be microorganisms in the form of bacteria, protozoa, or fungi. These microorganisms are processing the organic material for their own metabolic needs. This means that either their waste products must be useful or the process must be modified to collect usable and useful byproducts.

At the present time, biochemical processes are still mainly in the research and engineering laboratory stage. They provide, with respect to the conversion of grains and grasses, interesting facts which suggest further study to determine if they have economically valid applications to the production of usable energy from cellulosic agricultural products.

The major emphasis in biochemical processing has been in the area of the conversion of organic solid wastes into yeast or fungal protein. These studies are based on the existing and viable yeast dependent industries such as brewing. The studies done so far consider pilot plants or computer modeling of plant processes.

Two specific biochemical processes which have shown promise are the production of protein from bagasse, and the production of glucose from cellulose. The production of single cell protein by use of a specially designed chemical microbial plant applied to bagasse has been studied. The purpose of the study was to take previous laboratory data and apply these results to a pilot plant. From this pilot plant, both sizing and economic studies could be done to determine the expected characteristics for a full-sized industrial plant. The pilot plant was designed so that the fermentation operation could be carried out using both batch and continuous flow production.

The conversion of cellulose to glucose, and thus to other materials, also offers a possible method of recovering energy from cellulose and waste paper fractions of solid waste. An example of this type of research is that being done by the U.S. Army at Natick Laboratories. The enzymatic hydrolysis of cellulose is based on the use of a biological catalyst. In the case of this work, cellulose enzymes are used to hydrolyze cellulose to glucose.

Detailed studies of preprocessing, sizing and feed composition on the conversion time from cellulose to glucose need to be made for many different types of materials and especially for cellulosic agricultural products. Hopefully a description of a pilot test plant will soon be available. The results of the detailed studies of materials will enable a determination to be made of the range of applicability for enzymatic cellulose hydrolysis.

Since enzymatic hydrolysis is still in the developmental stage, much more research needs to be done. Also, further research should be done on mutant microorganisms or mixtures specifically adapted to the conversion of agricultural crops more efficiently.

5. Future work on conversion systems: The purpose of the foregoing analysis was to identify the most promising conversion processes for use with grains and grasses. Because very little direct work has been done in this area, the related conversion technologies of coal, solid waste, and biodegradation were reviewed. Based on the results of this initial screening process, it is intended that the following activities will be pursued for each of the selected conversion processes:

- Obtain process flow schematics of the selected conversion processes. This will permit an assessment of the operating characteristics of the system, and provide guidelines as to the process requirements which the biomass would be expected to pass.

- Determine the physical and chemical characteristics of the various grain and grass species. This information will then be used to evaluate the compatibility of these species with the selected conversion processes.

- Determine the mass throughput rates for each of the selected conversion processes. This information will be used to determine the surrounding area requirements for sufficient biomass material to fuel the plant, and will also be used to determine the energy output of the conversion process.

- Obtain an approximate estimate of the cost of each of the selected conversion processes. This information will be coupled with the mass throughput rates of biomass and the energy output to assess the economic size of the area served by the particular conversion plant.

D. Data Management System

In order to conduct an assessment of biomass production from grasses and grains, a data management system is needed to facilitate the general task of organizing and quantifying production capabilities throughout the U.S.

1. Data management system characteristics: The data management system will have the following capabilities:

a. The capability to inventory land in terms of its production capabilities and location.

b. The capability to distinguish features of the land resource which constrain the production system, i.e., characteristics which favor one type of biomass species over another, or which place restrictions on cultural practices.

c. The capability to display characteristics, such as rainfall, insolation and seasonal temperatures, which affect production capabilities and species adaptability.

d. The capability to display adapted species for various regions of the country, specific to the characteristics of the land resource, i.e., by land capability classes and subclasses.

e. Information on yields of adapted species, expressed either as whole plant biomass or residue biomass, on a per acre basis.

f. Information on production yields of adapted species for total acreages of suitable land in a geographical area.

g. Miscellaneous supporting information related to cost and yield, such as costs of planting and harvesting, fertilizer needs, and pest control needs.

h. The capability to accept and process information on unusual plant species, and translate the information into production capabilities for various geographical areas.

2. <u>Description of data management systems</u>: We are in the process of organizing a data management system which will be a relatively simple outgrowth of an existing system developed by MRI in an EPA study of nonpoint pollution. This system contains much of the needed information, in a form which we can immediately use, and we will add additional information and develop sobroutines as needed to carry out specific tasks on the program.

An important addition to this system will be the data being provided by Stanford Research Institute relating to crop residues, from their NSF/ERDA study which we expect to receive on tape soon. It will be delivered in a computer format compatible with MRI's present system.

Some of the information presently stored in the MRI system is listed below.

a. The 1967 Conservation Needs Inventory, which contains a large quantity and variety of data on agriculture production, on a county basis.

b. Land Resource Area (LRA) data, allocated to counties:

(1) Soil classificiations.

(2) Soil erodibility data, by land capability classes.

(3) Rainfall and rainfall erosivity.

(4) Topographic information.

(5) Temperature and humidity data.

c. Agricultural Stabilization and Conservation Service (ASCS) tapes on conservation practices implemented and their costs, by county, in the early 1970's.

d. Data on nitrogen, phosphorus, and organic matter contents of soils, assigned to counties.

e. Calculated/reported soil erosion yields, for basic classes of land, and for various categories of cropland and grassland

f. Acreages of crops, by county, and yields which can be readily translated into per acre yields. This information contains the mix of crops and grasses which are customarily grown in the area, on the county basis.

g. Acreages of land which fits various classifications, from submarginal to lands with essentially no limitations to production.

Perhaps the aspect of this system of greatest importance to the program is its organization with the county as the basic unit, coupled with the built-in capability to aggregate county information into larger geographical units: minor basins (subareas); aggregated subareas (ASA's), 99 in number; major basins; and states. In addition, it will be possible to aggregate the outputs by agricultural production regions, which range in number from about 10 to 20 depending on the system one uses. The subareas, each about 1/220 of the country (about 5 per state), would appear to be about as small an areas as one would wish to analyze as a reasonably homogeneous production unit. The aggregated subareas are expected to be representative of what can be termed small production "regions," regions which can be analyzed conveniently in terms of overall project objectives, i.e., determining production capabilities with various plant species, analyzing costs of production, biomass processing, storage and handling exclusive of conversion to fuel, and transportation to an appropriate conversion facility. However, the data management system will permit us to readily aggregate and evaluate the overall production capability of production areas of varying sizes, and optimize these in terms of production and cost. Having the county as the basis unit thus provides a flexibility which we feel will be quite important.

We are currently extracting from this data bank information on production of crops which fall in the whole plant category. These consist of acreages devoted to hay production, both native grasses and cultivated grass or hay; corn grown for silage; corn hogged or grazed; sorghums grown for silage; sorghums hogged or grazed; and hay and grasses grown for silage or grazing purposes. This information, reported at the county level, is being aggregated to ASA's, with total acreages, total yields, and yields per acre being reported out. This exercise is essentially a test run to check out system capabilities. The output will, however, fill an important information void, and will serve as a starting point for an overall analysis of biomass production from grasses and grains.

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APPENDIX 1

SYSTEMS STUDY OF FUELS FROM GRAINS AND GRASSES,
PHASE I BIOMASS PRODUCTION
FINAL REPORT CONTENT

I. Summary of Study Results

II. Background/Introduction

III. Assumptions/Definitions

A. Grains and Grasses Defined

B. Land Types

1. Crop lands--Class I, II, III, soils currently in agricultural production

2. Marginal lands--Class IV soils, and Class I, II, III not in agricultural production

3. Submarginal lands--Class V-VIII soils

C. Residue Biomass from Agricultural Crop Species

1. Sources--SRI agricultural crop residue study; census of agriculture, 1971-1973 data

2. Grain and grass crop species to be included in study

3. Grain and grass crop species to be excluded from study

a. Food crops

b. Fiber crops

c. Forage crops

D. Level of Detail

1. Geographic--county (region)

2. Temporal--annual yield

E. Whole Plant Biomass

1. Agricultural food crop species to be included in whole plant biomass

2. Agricultural forage crop species to be included in whole plant biomass

3. Other whole plant biomass species to be included in study

IV. Conversion Processes for Biomass

A. Characteristics of Alternative Processes (include "state of art")

B. Input Biomass Requirement Characteristics for Each Alternative Process/"Model" Facility

C. Compatibility of Residue Biomass From Each Crop Category to Each Conversion Process

V. County/Regional Data (Current and Forecast)

A. Climatological Data

1. Temperature

2. Water

3. Insolation

4. Wind

B. Land Use/Ownership Data

1. Soil class distribution

2. Land use distribution

3. Land ownership distribution

C. Energy Supply/Demand Data

1. Energy supply by type resource

2. Energy demand by type resource

D. Economic Data

1. Energy price by type resource

2. Agricultural crop price by type

3. Transportation costs

4. Storage costs

5. Alternate use value of biomass

6. Equipment costs

7. Irrigation costs

E. Identification of Growing Regions

1. Rationale for region selections

2. Specification of regions

VI. Residue Biomass Available from Grain and Grass Agricultural Production

A. Production Potential from Current (1971-1973) Cultural Practices

1. Estimated annual residue biomass yield

a. Rank order: tons/crop type/county

b. Rank order: total tons/all crop types/county

2. Estimated usable residue biomass from grains and grasses

B. Collection, Storage and Transportation Requirements

1. Discussion: crop type/county (region)

2. Costs per ton for collection, storage, transport

C. Fuel Production from Residue Biomass

1. Physical and chemical characteristics of residue biomass from each crop type

a. Discussion (energy content, physical characteristics, chemical characteristics)

b. Tables

2. Regional analysis

a. Number of counties (acres) needed to support alternative conversion processes in each region

(1) Tables

(2) Selected map displays

b. Potential contribution to regional energy needs

D. Alternative Scenarios for Residue Biomass Production from Agricultural Crops

1. Modified cultural practices (address VI A, B, C above as appropriate)

2. Modified strains to increase residue yield (same as above)

3. Residue biomass production incentives (same as above)

E. Analysis of Residue Biomass Potential from Grains and Grasses for Production of Energy

1. Discussion

a. Impact on soils of residue removal

b. Net energy analysis

c. Resource requirements

d. Economic considerations

e. Equipment needs

2. Graphical displays

3. Findings

F. Conclusions

VII Whole Plant Biomass from Grain and Grass Agricultural Crops

A. Whole Plant Biomass Potential from Current Food and Forage Production if All Converted to Fuel (Current Crop Land)

1. Tons/acre/crop/county (Class I, II and III soils)

2. Total tons/all crop types/county (I, II, III)

B. Whole Plant Biomass Potential from Current Food and Forage Crops Grown on Marginal Land (Class IV Soils)

1. Tons/acre/crop/county (Class IV soils)

2. Total tons/all crop types/county (IV)

3. Additional considerations of cultivation of marginal land (IV soils)

a. Costs of cultivation and harvesting by crop type/county

b. Equipment needs by crop type/county

c. Erosion considerations crop type/county

d. Water/irrigation requirements by crop type/county

C. Collection, Storage and Transportation Requirements

1. Discussion: crop type/county (region)

2. Costs per ton for collection, storage, transport

D. Fuel Production from Whole Plant Biomass from Agricultural Crops

1. Physical and chemical characteristics of whole plant biomass from agricultural crops

a. Discussion (energy content, physical characteristics, chemical characteristics)

b. Tables

2. Regional analysis

a. Number of counties (acres needed to support alternative conversion processes in each region

(1) Table

(2) Selected map displays

b. Potential contribution to regional energy needs

E. Analysis of Whole Plant Biomass Potential from Grain and Grass Agricultural Crops for Production of Fuels

1. Discussion

a. Impact on soils of residue removal

b. Net energy analysis

c. Resource requirements

d. Economic considerations

e. Equipment needs

2. Graphical displays

3. Findings

F. Conclusions

VIII. Whole Plant Biomass from Selected Energy Crop Species

A. Whole Plant Biomass Potential from Energy Plant Species Grown on Current Crop Land (Class I, II, III Soils)

1. Tons/acre/species/county (region/Class I, II, III soils

2. Btu/acre/species/county (region)/I, II, III

B. Whole Plant Biomass Potential from Energy Plant Species Grown on Marginal Land (Class IV Soils)

1. Tons/acre/species/county (region)/Class IV soils

C. Collection, Storage and Transportation Requirements

1. Discussion: crop type/county (region)

2. Costs per ton for collection, storage, transport

D. Fuel Production from Whole Plant Biomass from Energy Crop Species

1. Physical and chemical characteristics of whole plant biomass from agricultural crops

a. Discussion (energy content, physical characteristics, chemical characteristics)

b. Tables

2. Regional analysis

a. Number of counties (acres) needed to support alternative conversion processes in each region

(1) Tables

(2) Selected map displays

b. Potential contribution to regional energy needs

E. Analysis of Whole Plant Biomass Potential from Energy Crop Species for Production of Fuels

1. Discussion

a. Impact on soils of residue removal

b. Net energy analysis

c. Resource requirements

d. Economic considerations

e. Equipment needs

2. Graphical displays

3. Findings

F. Conclusions

IX. Case Study of Selected Mix of Food/Energy Farm Production in a Selected Region

A. Description of Counties/Farms to Provide Biomass for Conversion Facilities

B. Farm Management--Food Crops/Residue Biomass/Whole Plant Biomass Production for Each Farm

C. Economic Analysis

D. Conclusions

X. Recommendations for Additional Research

APPENDIX 2

DESCRIPTION OF SPECIES OF GRASSES, CEREAL GRAINS AND LEGUMES GROWN IN THE UNITED STATES

This appendix briefly presents information on numerous types of grasses, field crops and forage legumes. The information is presented as a frame of refernece for continuing work in the program. We do not expect to develop a complete treatment of potential for grain and grass production on a species by species basis, but will instead develop an analysis based on generally adapted species for different regions of the country, supplemented by an analysis of possibilities, where appropriate, of increasing biomass production by introduction of higher yielding types of plants.

a. Grasses: This section enumerates the characteristics and regional adaptation of numerous grass species and varieties. These species are grown for livestock grazing or for hay production. The seeds are usually of no value except for propagating new or improved stands of grasses.

The characterization of grass species and varieties as related to soils is not specific, because the interaction with climatic factors may greatly vary the growth responses of the plants to any set of soil conditions. Unfavorable factors may greatly vary the growth responses of the plants to any set of soil conditions. Unfavorable factors such as acidity, alkalinity, salinity, and texture, which affect the adaptation of species, within limits may be compensated for by optimum conditions of other factors, such as moisture.

BERMUDA-GRASS (Cynodon dactylon) grows in shallow to deep, highly acid to neutral soils and is tolerant of high salinity. It likes gravelly loam to well-drained clay. It tolerates drought periods but prefers heavy moisture. It is adapted to the Southern and Southwestern states. Coastal and Suwannee are better adapted to deep sands. Midland is hardier. Greenfield grows better at low nutrient levels.

BLUEGRASSES (Poa) comprise many perennial species, which are adapted to a wide range of soil and climatic conditions and are widely distributed throughout the United States.

Big bluegrass (P. ampla) grows in slightly acid to slightly alkaline soils. It is not tolerant of salinity. Soils should be of average depth, gravelly loam to well-drained clay. It prefers moist conditions, although it tolerates drought. A perennial, it is adapted to the Northwestern states.

Bulbous bluegrass (P. bulbosa) grows in moderately acid to slightly alkaline soils. It is not tolerant of salinity. Deep or moderately deep silt loam to poorly drained clay are suitable. It needs moist to very moist conditions. It is adapted to cool-summer temperatures. It is a perennial and is grown mostly in the coastal section of the West.

Canada bluegrass (P. compressa) grows in highly acid to neutral, shallow or moderately deep, loamy sand or poorly drained clay. It tolerates moist to very moist conditions but is not tolerant of salinity. This perennail is adapted mostly to the humid Northeastern states and grows at relatively low nutrient levels.

Kentucky bluegrass (P. pratensis), a perennial, grows in slightly acid to slightly alkaline soils of average depth, deep silt loam, and well-drained clay. It needs moist to very moist conditions. Available phosphorus and calcium stimulate growth. It is adapted to the Northern states and upper South, particularly in places where available phosphorus is abundant. It is adversely affected by high summer temperatures.

The rough bluegrass (P. trivialis) is a perennial that grows in moderately acid to neutral soils of shallow to average depth. Sandy loams to poorly drained clays are preferred. It is adapted to cool conditions of the Northern states. It is somewhat tolerant of shade.

BLUESTEM GRASSES, of many species, differ widely in adaptation to soil conditions. They grow in slightly acid to moderately alkaline soils. They are adapted to a wide range of climatic conditions and are grown mainly in the Great Plains.

The following are the more important perennial bluestems.

Angleton grass (Andropogon nodosus) grows in moderately acid to neutral soils of average depth to deep, fine sand, and poorly drained clays. It is tolerant of high salinity. It requires moist to heavy-moisture conditions, but may survive periods of draught. It is adapted to the gulf coast region.

Australian bluestem (A. intermedius) grows in fine sand to sandy loam of average depth. It is drought resistant, and adapted to the southern Great Plains.

Big bluestem (A. geradi) grows in slightly acid to slightly alkaline soils and in sandy loam to poorly draimed clay of average depth. It tolerates dry to moist conditions. It is adapted to the central Great Plains.

Little bluestem (*A. scoparius*) is winter hardy. It is adapted to the northern Great Plains, to sandy soils on the southern high plains, and to clay and sandy soils with good moisture.

Sand bluestem (*A. hallii*) grows in deep, fine sand to silt loams. It is adapted to conditions in the central and southern Great Plains.

Yellow bluestem (*A. ischaemum*) is tolerant of moderate salinity, is drought resistant, and is particularly adapted for use on eroded soils.

BROMEGRASSES (*Bromus*) include many species of perennials and annuals, which grow under widely different conditions. The perennials are adapted to the Northern states. The winter annuals grow in the South and the Western Coastal sections.

Field bromegrass (*B. arvensis*) grown in moderately acid to neutral soils and is not tolerant of salinity. Shallow to deep, sandy loam, to poorly drained clay and moist to heavy-moisture conditions are preferred. It is a winter annual in Eastern and Pacific states.

Harlan bromegrass (*B. stamineus*) is a winter annual in California.

Meadow bromegrass (*B. erectus*), a perennial, is widely distributed in the Northern states.

Mountain bromegrass (*B. carinatus*) grows in slightly acid to slightly alkaline soil and is not tolerant of salinity. It grows in shallow to deep fine sand to clay soils and requires moist conditions. This perennial is adapted to the Rocky Mountain and Pacific coastal regions.

Rescuegrass (*B. catharticus*) is adapted to the coastal section of the Western states and the lower South. It is a winter annual or a short-lived perennial.

Smooth bromegrass (*B. inermis*) grows in moderately acid to moderately alkaline soils, and does best on deep sandy loam and well-drained clays that are moist. A perennial, it is widely adapted in the Central and Northern states.

BUFFALOGRASS (*Bunchloe dactyloides*) grows in slightly acid to moderately alkaline soils. It needs shallow to moderately deep loam or well-drained clays and dry to moist conditions. It is drought resistant and is benefited slightly by applications of nitrogen. A warm-season perennial, it is particularly adapted to the heavy soils of the Great Plains.

BULBOUS BARLEY (Hordeum bulbosum) grows in neutral to moderately alkaline soil. It grows in sandy loam to clay loam of shallow or average depth. It needs moist to very moist conditions but will tolerate drought periods. It grows in winter, is adapted to the central part of the coastal region of the West, and is useful for eroded soils.

CANARYGRASSES include many perennial and annual species of Phalaris. They grow under a wide range of soil and climatic conditions.

Hardinggrass (P. tuberosa var. stenoptera) grows in slightly acid to highly alkaline soils. It thrives in moist or very moist silt loam or poorly drained clay of average or greater depth. It grows in winter and spring; in summer it remains domant in the tuber stage. It grows in heavy soils in Oregon and California and to a limited extent in the Gulf Coast section of Texas.

Reed canarygrass (P. arudineacea), a perennial, grows in slightly acid to neutral, shallow to deep, silt loam to muck in moist or swampy conditions. It is widely grown in the Northern states.

CARPETGRASS (Axonopus affinis) grows in highly acid to slightly acid soils of shallow to average depth and of fine sand to clay loam. It requires a great deal of moisture and tolerates swampy conditions. It is widely grown in the Gulf Coast section of the South. It is a perennial, warm-season grass, particularly adapted to low-lying sands.

Centipedegrass (Eremochloa ophiuroides) grows in highly acid to neutral soils and is not tolerant of salinity. It needs shallow to deep, gravelly loam to loam and moist to very moist conditions. It is used mainly as a lawn grass and is best adapted to the sandy soils of the Southern states.

Desert saltgrass (Distichlis stricta) grows in slightly acid to highly alkaline soils. It grows in loam or poorly drained clay of shallow to average depth and moist to swampy conditions. It will tolerate drought, however. A perennial, it is adapted to the inter-mountain and west coast states.

DROPSEEDS include many species of Sporobolus, which grow in a wide range of soil and climatic conditions. They are adapted to the southern Great Plains and the Southwestern states.

Alkali sacaton (S. airoides), a perennial, grows in neutral to highly alkaline soil. It prefers fine sand to clay loam and stands dry conditions.

Sacatongrass (S. wrightii) is less tolerant of alkaline and saline conditions and requires more moisture than alkali sacaton.

Sand dropseed (S. cryptandrus), a perennial, grows in neutral to moderately alkaline soil. It is tolerant of dry conditions.

FESCUE (Festuca species) is adapted tp a wide range of soil and climatic conditions in the Northern states and in the South at higher altitudes.

Arizona fescue (F. arizonica) grows in slightly acid to neutral soil of shallow to average depth, silt loam to clay loam, and dry to moist conditions. It grows in open pineland and is adapted to high altitudes of the Southwestern states.

Idaho fescue (F. idahoensis) grows in slightly acid to slightly alkaline soil of average depth, loamy sand to well-drained clay, and dry to moist conditions. It is adapted to cool to cold temperatures in the Central and Northern intermountain states.

Meadow fescue (F. elatior) grows in highly acid to neutral soil of shallow to average depth, silt loam to poorly drained clay, and moist conditions. It is adapted to humid parts of the Central states and the Pacific Northwest coastal region.

Red fescue (F. rubra) grows in moderately acid to neutral soils. It grows in deep, sandy loam to well-drained clay. It needs moist to very moist conditions and is adapted to the Northern states.

Sheep fescue (F. ovina) grows in highly acid to neutral soils. It prefers gravelly loam and well-drained clay. It is used mainly as a lawn grass and is adapted to shady sites in the Northern states.

Hard fescue (F. ovina var. duriuscula) will tolerate drier sites and lower nutrient levels than sheep fescue.

Tall fescue (F. arundinacea) grows in highly acid to moderately alkaline soils. It needs shallow to deep, gravelly loam to poorly drained clay, and moist to very moist conditions. It is widely adapted in the North, upper South, and Southwest. It will tolerate short periods of drought.

FOXTAIL millet (Setaria italica) grows in moderately acid to slightly alkaline soils. Deep, sandy loam to well-drained clay, moist to very moist, are preferred. Applications of nitrogen are beneficial. It is a summer annual and is widely adapted throughout the Northern states and the Great Plains. It will tolerate short periods of drought.

GRAMAGRASSES include many species of Bouteloua. The most important are perennials. They grow in neutral to moderately alkaline soil. They require soils of average depth--silt loam to well-drained clay--and dry to moist conditions. They are adapted to the Great Plains and intermountain regions.

Black grama (B. eriopoda) tolerates slight salinity and is more drought resistant than other gramagrasses.

Blue grama (B. gracilis) is widely adapted, from relatively moist to dry conditions and to sandy and hard lands.

Hairy grama (B. hirsuta) is particularly adapted to sandy, rocky, caliche soils.

Side-oats grama (B. curtipendula) requires more moisture than blue grama.

JAPANESE MILLET (Echinochloa crusgalli var. frumentacea) grows in moderately acid to neutral soils. Soils should be of shallow to average depth and sandy loam to well-drained clay. It needs heavy moisture. A summer annual, it is adapted to the Northeastern states.

JOHNSONGRASS (Sorghum halepense) grows in slightly acid to slightly alkaline soils. Soils should be of average to deep silt loam to poorly drained clay, moist to very moist. It is adapted to the Southern states. A perennial, it grows well in fertile soils.

MEADOW FOXTAIL (Alopecurus pratensis) grows in moderately acid to neutral soils. It needs soil of average depth to deep, silt loam and clay loam and moist to very moist conditions. It tolerates flooding. It is a perennial cool-season grass, particularly adapted to the Pacific Northwest.

MESQUITEGRASSES (Hilaria) include several species that grow in neutral to moderately alkaline soils and are tolerant of moderate salinity. They grow in shallow to deep sandy loam to clay loam, in very dry or dry conditions. They are perennials and are adapted to dry conditions of the Southwest. Common species are, curly-mesquite (H. belangeri), Galleta (H. jamesii), and Tobosa (H. mutica).

NEEDLEGRASS (Stipa) has many species that are adapted to wide range of soil and climatic conditions. They are generally adapted to the northern Great Plains and the intermountain and Pacific Coast regions.

Green needlegrass (S. viridula) is a perennial, adapted to the northern Great Plains.

Needle-and-thread grass (S. comata) grows in neutral soils to moderately alkaline soils. Soils should be shallow to moderately deep, sandy loam to well-drained clay. It stands dry to moist conditions. It is adapted to the northern Great Plains and intermountain regions.

Purple needlegrass (S. pulchra) is adapted to coastal ranges of the West.

ORCHARDGRASS (Dactylis glomerata) grows in moderately acid to neutral soils. It prefers shallow to deep gravelly loam to poorly drained clay, and moist to very moist conditions. It is a perennial and is widely adapted in the northern states and the upper South.

PANICUM GRASSES (Panicum) include many annual and perennial species, which are adapted to a wide range of soil and climatic conditions. They are widely distributed, mainly in the warmer climates.

Blue panicgrass (P. antidotale) grows in moderately acid to slightly alkaline soils. Sandy loam to well-drained fertile clay of average or greater depths are preferred. It is adapted to southern parts of the Great Plains and the Southwest. It is drought resistant but not winter hardy.

Guineagrass (P. maximum) grows in highly acid to slightly acid soils. A perennial, it is adapted to subtropical and tropical conditions and requires applications of nitrogen.

Panagrass (P. purpurascens) grows in highly acid to neutral soils. It requires moist to very moist conditions and tolerates some flooding. It is subtropical to tropical in adaptation, it is a perennial, and is propogated vegetatively.

Proso millet (P. miliaceum) grows in moderately acid or neutral shallow or deep, sandy loam soils in dry to moist conditions. A summer annual, it is cultivated for seed in the Central and northern Great Plains.

Switchgrass (P. virgatum), a perennial, is adapted mainly to the central and southern parts of the Great Plains. It prefers sandy loams that are reasonably well supplied with moisture.

Vine mesquitegrass (P. obtusum) grows in neutral to moderately alkaline soils. Soils should be of shallow to average depth and sandy loam to well-drained clay. A perennial, it grows in the Southwestern states and is drought resistant.

PENNISETUM GRASSES (Pennisetum) include many annual and perennial species, which grow in a wide range of soil and moisture conditions. They are adapted to climates in the South.

Buffelgrass (*P. ciliare*), are perennial, grows in slightly acid to slightly alkaline soils. Soils should be of average depth, fine sand to well-drained clay. It stands dry to moist conditions and is moderately drought resistant. It grows in southern Texas and is particularly adapted to sandy soils. It requires applications of nitrogen. Blue buffel is better on heavy soils.

Kikuyugrass (*P. clandestinum*) is a perennial that grows in neutral to moderately alkaline soils. Shallow to deep, fine sand to well-drained clay are preferred. It is adapted to subtropical and tropical conditions, principally California.

Napiergrass (*P. purpureum*) grows in highly acid to neutral soils. Its preferred soils are of average depth, deep, fine sand or clay loam. This perennial requires moist or very moist conditions. It is adapted to subtropical or tropical conditions, principally Florida.

Pearl millet (*P. glaucum*) grows in highly acid to neutral soils. Deep, fine sand or loam are best. It requires a great deal of moisture and is benefited by nitrogen. It is a summer annual adapted to the South.

PERENNIAL VELDTGRASS (*Ehrhartacalycina*) grows in neutral to moderately alkaline soil. It is tolerant of slight salinity and likes shallow to deep loam and well-drained clay and dry to moist conditions. It is adapted to central and coastal areas of California. It is a drought-resistant perennial.

REDTOP AND BENTGRASSES (*Agrostis*) include many species that grow in highly acid to neutral soils. Shallow, moist, gravelly loam to muck are preferred. They tolerate swampy conditions and benefit from the application of nitrogen. They are cool-season grasses and are suited to humid sections of the Northern states.

Colonial bentgrass (*A. tenuis*), creeping bentgrass (*A. palustris*), and redtop (*A. alba*) are important perennials.

RHODEGRASS (*Chloris gayana*) a perennial, grows in moderately acid to highly alkaline soils. Soils of average or about average depth, loam and well-drained clay are preferred. It tolerates dry conditions.

RICEGRASSES (*Oryzopis*) comprise many species, which grow in slightly acid to moderately alkaline soils. They thrive in sandy loam to clay loam that is of average depth or deeper. They stand very dry to dry condtions and are tolerant of wide ranges of temperature. They are mainly adapted to the western intermountain region.

Indian ricegrass (O. hymenoides) is drought resistant. It is a perennial.

Smilo (O. miliacea) tolerates dry or moist conditions. It is grown in California in places that have wet winters and dry summers.

RYEGRASSES are annual and short-lived perennial species of Lolium. They grow in highly acid to neutral soils. Shallow to deep, fine sand to poorly drained clay soils are suitable, as are moist to very moist conditions. Some species are widely adapted in most states.

Italian ryegrass (L. multiflorum) is adapted as a winter annual in the South and as a summer annual in the North.

Perennial ryegrass (L. perenne) is a short-lived perennial. It is adapted to conditions of the Pacific Northwest and limited areas of the Northeast.

ST. AUGUSTINEGRASS (Stenotaphrum secundatum), a perennial, grows in highly acid to slightly alkaline soils. It grows in shallow to deep, gravelly loam to muck soils in wet or swampy conditions. It is adapted to the Gulf Coast region.

SUDANGRASS (Sorghum sudanense) grows in moderately acid to neutral soils of average depth or deep, loamy sand to well-drained clay. It requires moist conditions although it tolerates drought periods after it is established. It is a summer annual adapted to localities with high summer temperatures.

TALL OATGRASS (Arrhenatherum elatius) is a short-lived perennial that is grown in moderately acid to neutral soils. Soils should be of shallow to average depth and loam to poorly drained clay. It requires moist to very moist conditions but thrives in rich, well-drained soils. It is adapted to the Northern states.

TIMOTHY (Phleum pratense) grows in highly acid to neutral soils. It is benefited by applications of nitrogen. It is widely adapted in the Northern states in sandy loam or poorly drained clay.

VELVETGRASS (Holcus lanatus) grows in highly acid to slightly acid soils. Soils should be of shallow to average depth and fine sand to poorly drained clay. It requires heavy moisture. It is benefited by applications of nitrogen, although it grows at a low nutrient level. It is adapted to the Northern states and the upper South. It will tolerate swampy sites. It is generally viewed as a weed.

WHEATGRASSES (Agropyron) include many native and introduced species. They grow under a wide range of soil conditions but are not adapted to acid soils. Some species tolerate salinity and are adapted to drier sites. They are widely distributed in the Western states.

BLUEBUNCH Wheatgrass (A. spicatum) requires semihumid conditions and a higher nutrient level.

Crested wheatgrass (A. desertorum) grows in neutral to slightly alkaline soils. It is tolerant of gravelly loam or well-drained clay soils of average depth, and prefers dry to moist conditions.

Beardless wheatgrass (A. inerme) is slightly more tolerant of drought in the Pacific Northwest, where it is best adapted, than crested wheatgrass.

Fairway wheatgrass (A. cristatum) is better adapted to extreme northern conditions than crested wheatgrass.

Intermediate wheatgrass (A. intermedium) is less drought tolerant and requires a higher nutrient level. It is adapted to well-drained, sandy loam to clay loam. It is less hardy.

Pubescent wheatgrass (A. trichophorum) tolerates a lower nutrient level than intermediate wheatgrass.

Quackgrass (A. repens) grows in highly acid to neutral soils. Soils should be of average depth to deep, fine sand to clay loam. It demands moist to very moist conditions.

Siberian wheatgrass (A. sibericum) is better adapted to sandy soils having hardpans than crested wheatgrass.

Slender wheatgrass (A. trachycaulum) requires more moisture than crested wheatgrass.

Streambank wheatgrass (A. riparium) is tolerant of heavy moisture. It forms dense sod for waterways.

Tall wheatgrass (A. elongatum) tolerates poor drainage and high salinity.

Western wheatgrass (A. smithii) is adapted to moist swales and a wide range of climatic adaptation.

WILDRYE includes many perennial species of Elymus. They grow in a wide range of soil and climatic conditions. At least one species is found in nearly every state.

Canada wildrye (E. canadensis) grows in highly acid to moderately alkaline soils. It requires shallow to deep, gravelly loam to clay soils and moist to very moist conditions. It is a widely adapted species.

Giant wildrye (E. condensatus) grows in neutral to moderately alkaline soils. A perennial, it needs shallow to deep, stony loam to well-drained clay soils and very dry to moist conditions. It is moderately drought resistant and is widely distributed throughout the dry areas of the West.

Russian wildrye (E. junceus) grows in neutral to moderately alkaline soils. It requires soils of average or above average depth, sandy loam to clay loam, and dry to moist conditions and requires a high nutrient level. It is particularly adapted to the northern parts of the Great Plains and farther West.

Siberian wildrye (E. giganteus) grows in slightly acid to moderately alkaline soil. It tolerates dry to moist conditions. It is particularly useful for the stabilization of inland sand dunes but is not adapted to coastal conditions.

Blue wildrye (E. glaucus) grows on drier sites than Siberian wildrye.

The dry matter and mineral contents of selected grasses are shown in Table 1.

b. Field crops: Corn, wheat, soybeans, cotton, barley, oats, rice, and other cereal grain, oil and fiber crops comprise the backbone of agricultural food and fiber production. The general characteristics of these crops are summarized in this subsection.

Climate, rather than soil, is the chief factor in determining where most field crops are adapted. Crop plants with fine, fibrous roots, including wheat, oats, and barley, are best suited to medium or heavy soils.

Plants with thicker roots, such as corn and alfalfa, succeed well on sandy loam soils but also are well adapted to heavy soils.

Crops like grain sorghum often produce high yields on heavy soils in wet seasons in the drier regions but may fail on heavy soils in a dry year, when fair crops are obtained on sandy soils.

TABLE 1

TOTAL DRY MATTER AND MINERAL CONTENT OF SELECTED GRASS SPECIES

	Total Dry Matter (%)	Ash (%)	Ca (%)	P (%)	N (%)	K (%)
Bermuda Grass Hay	90.6	7.0	0.37	0.19	1.15	1.42
Bluegrass	89.4	6.5	0.46	0.32	1.31	1.73
Bluestem	86.6	5.4	--	--	0.86	--
Bromegrass	88.1	8.2	0.20	0.28	1.58	2.35
Buffalograss	88.7	10.1	0.70	0.13	1.09	1.36
Carpetgrass	92.1	10.2	--	--	1.12	--
Fescue	89.2	6.8	--	0.20	1.12	1.43
Foxtail Millet	87.6	6.7	0.29	0.16	1.31	1.70
Gramagrass	89.8	7.9	0.34	0.18	0.93	--
Japanese Millet	86.8	8.4	0.20	--	1.33	2.10
Johnsongrass	90.1	7.4	0.87	0.26	1.04	1.22
Needlegrass	88.1	6.2	--	--	1.15	--
Orchardgrass	88.6	6.8	0.19	0.17	1.23	1.61
Panicgrass	90.2	6.6	--	--	1.33	--
Proso Millet	90.4	3.3	0.05	0.30	1.90	0.43
Red Top	91.0	6.9	0.38	0.23	1.15	1.93
Rhodesgrass	89.0	8.5	0.35	0.27	0.91	1.18
Ryegrass	88.6	7.5	--	0.24	1.30	1.00
Sudangrass	89.3	8.1	0.36	0.26	1.41	1.30
Oatgrass Hay, tall	88.7	6.0	--	0.14	1.20	1.36
Timothy	89.0	4.9	0.23	0.20	1.04	1.50
Wheatgrass	90.0	6.7	0.30	0.24	1.28	2.41

Soils that are high in nitrogen are unsuitable for small grains because excessive nitrogen encourages lodging, the development of rust, and delays maturity.

The soil type has only a minor role in determining the adaptation of different varieties of a given crop, except as it affects the abundance of soil moisture or nitrogen. Differences in soil moisture, as influenced by local topography, however, may determine the best variety to be grown. Quick-maturing varieties having small plants thus may be best suited to rolling uplands, and larger slow-maturing varieties are best for rich bottomlands.

Corn (Zea mays) grows in well-drained, sandy to clay loam of a pH of 5.5 to 8 and 2 to 8 ft deep. Good fertility is essential for high yields, especially when corn is grown in thick stands. Corn responds well to abundant nitrogen. Calcareous soils are likely to be deficient in available potash and phosphorus.

Wheat (Triticum species) prefers well-drained silt loam or clay loam but will grow in fine sandy loam to clay--pH 5.0 to 8.5; depth 2.5 to 8 ft. It requires balanced fertility and ample available nitrogen to produce grain of high protein content.

Barley (Hordeum vulgare) requires a well-drained sandy loam to clay, which has a pH 6 to 8.5 and is 2.5 to 8 ft deep. It is very tolerant to salinity. It is more tolerant to sandy soil textures but less tolerant to acidity than are wheat and oats.

Rye (Secale cerale) is more tolerant of sandy soils than is wheat, oats, and barley. Rye grows in sand to clay soil of pH 4.5 to 8.5 and 3 to 8 ft deep.

Oats (Avena sativa and A. byzantina) grows in well-drained, fine sandy loam to clay, which has a pH of 5 to 8.5 and is 2.5 to 8 ft deep. Excessive soil nitrates favor lodging, and sometimes enough are absorbed by the plants to make oats hay poisonous to livestock.

Grain sorghum (Sorghum vulgare) requires well-drained sandy to clay soils 3 to 8 ft deep and having a pH of 5 to 8.5. In semiarid retions it succeeds best on silt loam or clay loam, loam soils in the wetter years and sandy soils in dry years. Lighter soils provide better water infiltration and reduced vegetative growth, which lessens injury from drought.

Rice (Oryza sativa) grows in loam to heavy clay (adobe) that has a retentive subsoil, a pH of 4.5 to 7.5 and is 2 to 3 ft deep. The soil must be wet or flooded. It is sensitive to salinity in excess of 500 grains/gal. of water. The potash requirement is low, but abundant ammonium nitrogen is essential to high yields.

Soybeans (*Glycine max*) grow in highly acid to slightly alkaline soils--shallow to deep, fine sand to muck. They need moist to heavy-moisture conditions and do not tolerate salinity. They are benefited by the application of mineral nutrients. Soybeans are adapted to most states except dryland regions and localities where cool daily temperatures prevail.

Cotton (*Gossypiim hirsutua* and *G. barbadense*) grows in soils that are sand to heavy clay, deep and well drained, reasonably high in organic matter, and pH 5.2 to 8. Its indeterminate fruiting habit permits it to mature the number of bolls that can be supported by the extent of vegetative growth. Limited nitrogen reduces both total growth and yield. Deficiencies of potash cause extreme earliness and premature defoliation. Phosphorus is necessary for adequate maturity.

Hops (*Humulus lupulus*) grows on deep, sandy, well-drained loam to loam soil, 6 to 8 in pH. Soil moisture must be adequate. Soils of high salinity are unsuitable.

Hemp (*Cannabis sativa*) requires well-drained loam, silt loam, or clay loam; pH 5 to 7; 3 to 6 ft deep.

Ramie (*Roehmeria nivea*) grows in loam or muck, pH 5 to 7 in reaction, and 2 to 4 ft deep. Abundant fertility is necessary for successive heavy crops through the season.

Dry matter and mineral contents of biomass derived from cereal crop grains and plant residues are shown in Table 2. The dry matter content of field dry matter is consistently in the 85 to 90% range. Ash and mineral contents are reasonably constant, at a few percent, with the exception of some plants or residues such as rice hulls and rice straw.

c. Forage legumes: A majority of the legumes are grown for hay and grazing, with a notable exception being soybeans. Some of the legumes are used extensively for roadside embankment stabilization and for decorative plus utilization purposes.

These legumes are particularly benefited by applications of calcium, phosphorus or potassium when the supply in the soil is exhausted or unavailable. Trace elements may have to be supplied to the plants for high yield or forage and seed and for persistence. Such needs are mostly of local occurrence and are related to soils of specific texture and origin.

Legumes vary in their ability to make growth at different levels of soil acidity and alkalinity, but slightly acid to neutral soils are generally best.

TABLE 2

TOTAL DRY MATTER AND MINERAL CONTENT OF CERAL CROP SPECIES

	Total Dry Matter (%)	Ash (%)	Ca (%)	P (%)	N (%)	K (%)
Corn						
Corn Cobs	90.4	1.6	--	0.02	0.37	0.37
Corn Fodders (w/ears)	91.1	6.4	0.24	0.16	1.25	0.82
Corn Husks, (dried)	85.0	2.9	0.15	0.12	0.54	0.55
Corn Stover	90.6	5.8	0.29	0.05	0.94	0.45
Corn Stalks	82.8	5.3	0.25	0.09	0.75	0.50
Corn Grain	85.0	1.2	0.02	0.27	1.38	0.27
Wheat Hay	90.4	6.4	0.14	0.18	0.98	1.47
Wheat Straw	92.5	8.3	0.21	0.07	0.62	0.79
Wheat Grain	89.5	1.9	0.04	0.39	2.11	0.42
Barley Hay	90.8	6.8	0.26	0.23	1.17	1.35
Barley Straw	90.0	6.0	0.32	0.11	0.59	1.33
Barley Grain	89.4	2.8	0.06	0.37	2.03	0.49
Rye Hay	91.3	5.0	--	0.18	1.07	1.05
Rye Straw	92.8	3.5	0.26	0.09	0.56	0.90
Rye Grain	89.5	1.9	0.10	0.33	2.02	0.47
Oat Hay	88.1	6.9	0.21	0.19	1.31	0.83
Oat Straw	89.7	6.3	0.19	0.10	0.66	1.34
Oat Hulls	92.8	6.5	0.20	0.10	0.78	0.48
Oats Grain	90.2	4.0	0.09	0.34	1.92	0.43
Grain Sorghum Fodder	88.8	7.1	0.34	0.12	0.99	1.29
Sorghum, Grain	89.4	4.3	0.03	0.20	1.81	0.36
Rice Hulls	92.0	19.1	0.08	0.08	0.48	0.31
Rice Straw	92.5	14.5	0.19	0.07	0.62	1.22
Rice Grain	89.8	5.2	0.08	0.32	1.26	0.34
Soybeans Hay	88.0	7.0	0.94	0.24	2.30	0.82
Soybeans Straw	88.8	5.1	NA	0.13	0.64	0.62
Soybean Grain	90.0	4.6	0.25	0.59	6.06	1.50
Cotton Bolls	90.8	0.61	6.9	0.09	1.39	3.18
Cotton Leaves	91.7	4.58	15.8	0.18	2.45	1.36
Cotton Stems	92.4	NA	4.2	NA	0.93	NA
Cotton Seed Hulls	90.7	0.14	2.6	0.07	0.62	0.87
Cotton Seed, Whole	92.7	0.14	3.5	0.70	3.70	1.11
Hop Spent Dried	93.8	NA	5.3	NA	3.68	NA
Ramie Meal	92.2	4.32	13.2	0.22	3.07	NA

Nitrogen is an essential nutrient for all legumes. Innoculated legumes can provide the nitrogen they require from the air through the interaction of compatible symbiotic nitrogen-fixing bacteria, which infect the roots and cause nodules to form on them.

Soil texture is an important factor among the water and temperature relationships that different species require for maximum growth. High yields of forage and seed and the persistence of plants reflect the interaction of favorable climatic and soil factors. Within limits, if the other factors are favorable, plants can tolerate one or more unfavorable conditions, which, however, cause variations in the range of responses.

ALFALFA (Medicago sativa) grows in slightly alkaline soils of average or greater depth, sandy loam to well-drained clay. It tolerates slight salinity, but it will not tolerate wet, poorly drained soil. Moist conditions are needed for seedling establishment.

Alfalfa tolerates periods of drought if moisture is available to the roots. It is benefited by application of mineral nutrients when needed. Its requirements of available minerals are high. It is widely adapted to different climates if proper varieties are used.

CLOVERS (TRUE) (Frifolium species) grow under a wide range of soil and climatic conditions. The many species of true clovers thrive in cool, humid climates and under irrigation. They are perennials and winter annuals. They have restricted use as summer annuals.

Alsike clover (Trifolium hybridum) grows in moderately acid to neutral soil. It needs shallow to deep, silt loam or much soils, and moist to heavy-moisture conditions. It tolerates swampy conditions for short periods. A perennial, it behaves as a biennial in the Northern states. It is particularly valuable for poorly drained soils. It is grown as a winter annual in Southern states.

Ball clover (Trifolium nigrescens) grows in moderately acid to neutral soils of shallow to average depth, and of fine sand to clay. It makes growth at a relatively low nutrient level. A winter annual, it is adapted to the Southern states.

Berseem clover (Trifolium alexandrinum) grows in slightly acid to slightly alkaline soil. It tolerates slight salinity in soils of average or greater depth, silt loams to poorly drained clays. It needs moist conditions. A winter annual, it is the least winter hardy of all clovers. It is grown successfully in southern California, Arizona, New Mexico and parts of southern Texas.

Cluster clover (Trifolium glomeratum) grows in moderately acid to neutral soils. Soils should be shallow or of average depth and fine sand to silt loam. It needs moist to heavy-moisture conditions and is best adapted to conditions of southern Mississippi. It is a winter annual and is restricted in adaptation.

Crimson clover (Trifolium incarnatum) thrives in soils that are moderately acid to neutral and shallow to deep, fine sand to well-drained clay. It needs moist to heavy-moisture conditions, but does not thrive in waterlogged soils. It is widely adapted as a winter annual in the southern and Pacific regions and as a summer annual in northern Maine.

Lappa clover (Trifolium lappaceum) grows in neutral to slightly alkaline soils and loam to poorly drained clays of shallow or average depth. Ample moisture is needed. It is a winter annual, specifically adapted to wet, heavy soils in the lower Southern states.

Large hop clover (Trifolium campestre) grows in moderately acid to neutral soils. Soils should be shallow to deep, ranging from gravelly loam to clay. Moist to very moist conditions are required, but nutrient levels can be relatively low. A winter annual, it is adapted to the Southern states and coastal sections of the West.

Small hop clover (Trifolium dubium) is more tolerant of unfavorable climate and low nutrient levels than large hop clover, but otherwise requires similar conditions.

Persian clover (Trifolium resupinatum) grows in slightly acid to slightly alkaline soils of average depth, deep silt loam, or poorly drained clay that are moist to very moist. It is a winter annual especially adapted to low, heavy, wet soils of the Southern states and coastal section of the West.

Red clover (Trifolium pratense) will grow in moderately acid to neutral soils, deep, sandy loam, and well-drained clay soils. It is a perennial but behaves mostly as a biennial in the Northern states or a winter annual in the South. It has wide adaptation throughout most of the United States. It needs plenty of moisture.

Rose clover (Trifolium hirtum) grows in slightly acid soils to slightly alkaline soils of shallow to average depth, silt loams, and well-drained clay. It needs moist to heavy-moisture conditions. A winter annual, it is adapted to hill sites of California rangelands.

Strawberry clover (Trifolium clagiferum) grows in neutral to slightly alkaline soil. It tolerates moderate salinity. It grows in shallow to deep, sandy loam to poorly drained clay. It needs moist to heavy-moisture conditions. It tolerates flooding. It is a perennial and is adapted to the poorly drained, salty soils of the Western states.

Striata clover (Trifolium striatum) grows in slightly acid to slightly alkaline soils of average or greater depth, loam to poorly drained clay. It requires moist to heavy-moisture conditions. It is a winter annual adapted to heavy, limy soils in the South.

Sub clover (Trifolium subterraneum) grows in moderate acid to neutral soils. It is not tolerant of salinity or waterlogged soils. It prefers shallow or deep, gravelly loam or well-drained clay. It is adapted to the coastal sections of the West and parts of the South. It is a winter annual. Varieties differ in adaptation to different soil conditions.

Whiteclover (Trifolium repens) grows in moderately acid to slightly alkaline soils. It needs shallow to deep, fine sand or poorly drained clays and moist to heavy-moisture conditions. It is widely adapted throughout most of the United States. A perennial, it behaves mostly as a winter annual in the South and as a biennial and perennial in the Northern states. Varieties differ in nutrient requirements for high production. Ladino has a high requirement of nutrients.

COWPEA (Vigna sinensis) grows in highly acid to neutral solis. It needs soils of shallow to average depth, fine sand to well-drained clay, and moist to heavy-moisture conditions. It is benefited by the application of mineral nutrients when needed, but it will grow at relatively low levels of nutrients. It is a summer annual and has many varieties. It is adapted to the South.

CROWN VETCH (Coronilla varia) grows in highly acid to neutral soils. Its soil requirements are not critical on gravelly loam to well-drained clay soils and moist to heavy-moisture conditions. Applications of mineral nutrients, are beneficial. It is a perennial and is unpalatable to livestock. It is adapted to a wide range of conditions in the Northern states.

FIELDPEA (Pisum sativum) is one species, of several types, which grow in moderately acid to neutral soils of average depth or in deep, fine sand or clay loam. It prefers moist to heavy-moisture conditions. It is benefited by the application of mineral nutrients, when needed. It requires cool temperatures. It is a summer annual in the Northern states and a winter annual in the Southern states. The Austrian winter fieldpea is more winter hardy than the other tyeps.

GUAR (Cyamopsis tetragonoloba) grows in moderately alkaline soils. It is tolerant of moderate salinity. Soils of average depth to deep, fine sand to well-drained clay loam are preferred. Guar requires moist soil for stand establishment; thereafter it will tolerate dry conditions. It is benefited by an application of mineral nutrients. A summer annual, it is adapted to the hot climate and long, dry growing season of the Southwestern states.

KUDZU (Pueraria lobata) grows in highly acid to neutral soils. It is not tolerant of salinity. Shallow to deep, gravelly loam and well-drained clay and moist to heavy-moist conditions are suitable. It is benefited by the application of mineral nutrients when they are needed, although the plants can utilize nutrients from relatively unavailable sources. It is a perennial with a viny type of growth. It is adapted to the Southern states.

LESPEDEZA (Lespedeza species) has several annual and perennial species that grow in highly acid to slightly acid soils but do not tolerate salinity. Shallow soils and soils of average depth and gravelly loam to clay loam soils are suitable. Moist to heavy-moisture conditions are needed. Mineral nutrients may be needed. It is grown mostly in the Southern states. It is tolerant of high summer temperatures and relatively low nutrient level and requires a relatively long growing season.

Bicolor lespedeza (L. bicolor) is a perennial, woody species, used mostly for erosion control and bird feed. It is adapted best to loam and clay soils.

Sericea lespedeza (L. cuneata) is a perennial that is less palatable than the annual species.

Striate lespedeza (L. striata) is an annual that requires a longer growing season than Korean lespedeza.

LUPINES comprise many annual and perennial species, which grow in highly acid to neutral soils and are not tolerant of salinity. Soils are shallow to deep, gravelly loam to loam. Moist to heavy-moisture conditions are needed. Applications of mineral nutrients may be beneficial, but the lupines grow at low nutrient levels.

Species of agricultural value are grown as winter annuals. They generally are adapted to the Gulf states. Some species are toxic to livestock.

Blue lupine (Lupinus angustifolius) is of two types - bitter blue, which is toxic to livestock, and sweet blue, which is palatable.

Yellow lupine (L. luteus) is the least hardy of the listed species.

White lupine (L. albus) is grown as a winter annual in the Southern states. It is hardier than blue lupine and yellow lupine.

MEDICKS OR BURCLOVERS comprise several species of Medicago. They grow in slightly acid to moderately alkaline soils. They like shallow to deep, sandy loam to well-drained clay and moist conditions. They are benefited by applications of mineral nutrients when needed. They require available calcium for best growth.

Most species behave as winter annuals. They are adapted to the limestone and neutral soils of the Southern states and coastal section of California.

Black medick (M. lupulina) is the most winter hardy of the listed species. It is a winter annual in the South and a summer annual in the North. It is less exacting in its calcium requirement than the other species, e.g, Buttonclover (M. orbicularis), California burclover (M. hispida), and Spotted medick (M. arabica).

PEAVINE comprises several species of Lathyrus, which grow in slightly acid to slightly alkaline soils but are not tolerant to salinity. Soils are shallow to deep, silt loam to poorly drained clays. It needs heavy moisture. Applications of mineral nutrients may be helpful. They are best adapted to heavy, wet soils of the southern and coastal section of the Western states.

Roughpea (L. hirsutus) is a winter annual, grown in the heavy, dark-colored soils of the Southern states.

Tangier pea (L. tingitanus), a winter annual, has a wide range of soil adaptation. It is used in the western coastal sections and Southern states.

RATTLEBOX Lance crotalaria (C. lanceolata), Slenderleaf crotalaria (C. intermedia), and Striped crotalaria (C. mucronata (striata)) are some of the species of Crotalaria. They grow in highly acid to neutral soil. They are not tolerant of salinity and require moist to heavy-moisture conditions. The plants will grow at relatively low nutrient levels, but fertilizers may be beneficial. They are summer annuals and are particularly adapted to the sandy soils of the Southern states.

SESBANIA (Sesbania exaltata) grows in highly acid to neutral soils. It is tolerant of slight salinity. The soils can be of shallow to average depth and gravelly loam or well-drained clays. Moist conditions are required for seedling establishment; thereafter plants tolerate periods of drought. Applications of needed mineral nutrients are beneficial, although plants grow at a relatively low nutrient level. It is a summer annual. It is adapted to the Southern Southwestern states.

SWEETCLOVER (Melilotus) includes two species that are widely grown. Slightly acid to moderately alkaline soils are needed. They will tolerate slight to moderate salinity and grow on shallow to deep, gravelly loan to poorly drained clay. Moisture is needed for stand establishment; after that they will tolerate dry conditions. Fertilization may be beneficial. The plants particularly require readily available calcium.

The two important species are widely grown throughout the United States whereever the soil is neutral or sufficient lime is spplied to correct acidity.

White sweetclover (Melilotus alba) has biennial and annual forms are used as winter annuals in the South and as summer annuals in the Northern states.

Yellow sweetclover (Melilotus officinalis), a biennial, will grow under slightly more adverse climatic conditions than white sweetclover.

TREFOIL includes several perennial and annual species of Lotus. Trefoil grows in moderately acid to neutral soil. It grows in soils of shallow or average depth-- sandy loam to poorly drained clay. Moist to very moist conditions are needed. It is adapted to the Northern states and tolerates short dry periods.

Birdsfoot trefoil (L. corniculatus) is more winter hardy than big trefoil. It is a perennial. Big trefoil (L. uliginosus) is less winter hardy than birdsfoot but is better adapted to swampy conditions. It is a perennial.

Narrowleaf birdsfoot trefoil (L. temuis) is a perennial and is more tolerant of high salinity.

VETCHES include many species of Vicia, which grow in highly acid to slightly alkaline soils. They are tolerant of slight salinity. Shallow to deep, fine sand to poorly drained clays and moist to heavy-moisture conditions are preferred. Some species are adapted to a wide range of climatic conditions.

Common vetch (V. sativa) is a winter annual in West Coast and Southern states

Hairy vetch (V. villosa) is a winter or summer annual. It is the most winter hardy of all the vetches.

Hungarian vetch (V. pannonica), a winter annual, is grown mostly in the milder climates of the West Coast.

TABLE 3

TOTAL DRY MATTER AND MINERAL CONTENT OF SELECTED LEGUMES

	Total Dry Matter (%)	Ash (%)	Ca (%)	P (%)	N (%)	K (%)
Alfalfa Hay	90.5	8.2	1.47	0.24	2.37	2.05
Clover, Alsike	88.6	7.8	1.15	0.23	1.94	2.44
Clover, Crimson	89.5	8.7	1.23	0.24	2.27	2.79
Clover, Red	88.1	6.4	1.35	0.19	1.89	1.43
Clover Sweet	92.2	11.0	--	NA	4.26	NA
Cropea Hay	90.4	11.3	1.37	0.29	2.98	1.51
Crown Vetch	89.0	6.2	1.18	0.32	2.13	2.22
Guar Hay	90.7	12.4	NA	NA	2.64	NA
Kudzu Hay	89.0	6.9	2.78	0.21	2.54	NA
Lespedeza, Annual	89,2	5.2	0.98	0.18	2.03	0.91
Lespedeza, Perennial	89.0	4.9	0.92	0.22	2.11	0.98
Bur Clover	92.1	10.1	1.32	0.45	2.94	2.96
Peavine Hay	86.3	6.8	1.48	0.16	1.90	NA
Hairy Vetch	88.0	8.5	1.13	0.32	3.09	1.96