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4. GROWN ORGANIC MATTER AS A FUEL RAW MATERIAL RESOURCE, FINAL REPORT

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16. Abstract

An extensive literature search was made on biomass production, and an annotated bibliography is presented in this report. Information gleaned was continuously evaluated from the standpoint of costs and energy requirements of biomass production of many species. Climatic zones and water and nutrient requirements for various species were considered. No exotic species were uncovered in this analysis that gave hope for a bonanza of biomass production under culture, location, and management markedly different from those of existing agricultural concepts. A simulation analysis of biomass production was carried out for six species using conventional production methods. The results of this type of analysis included production costs and energy requirements. These estimates of biomass production were compared with data on food, fiber, and feed production. The alternative possibility of using residues from food, feed, or lumber was evaluated. The conclusion was drawn that climate, land availability, economics of agricultural production and marketing, food demand, fertilizer shortage, and water availability all combine to cast great doubt on the feasibility of producing grown organic matter for fuel, in competition with food, feed, or fiber, on U.S. acreages. The feasibility of collecting residues may be nearer, but the competition for the residues for return to the soil or cellulosic production is formidable.

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SUMMARY

The original objectives of the work were: 1. Conduct a comprehensive survey of pertinent literature and research projects in order to (a) compile an annotated bibliography of published works on biomass production, (b) compile a listing of current research and (c) prepare charts, tables and graphs of pertinent information for the guidance of future experimentation. 2. Evaluate the information collected and design field experiments needed to confirm or supplement collected information.

An extensive literature search was made and an annotated bibliography prepared. Information gleaned was continuously evaluated from the standpoint of costs and energy requirements of biomass production of many species. Climatic zones, water and nutrient requirements for various species were considered. There were no exotic species uncovered in this analysis that gave hope for a bonanza of biomass production under markedly different culture, location and management from existing agricultural concepts.

Emphasis was shifted from the planning of field experiments to the simulation analysis of projected systems of biomass production using conventional production methods and 6 different candidate species with high production potential. These analyses produced estimates of costs and energy requirements of production, including the feedback of fuel cost as an input into the cost of biomass production. Economics of farming for biomass harvesting compared to food, feed or fiber production are presented along with the land availability, climate suitability, and input availability in the U.S. The alternate possibility of using residues from the production of food, feed or lumber is also evaluated.

The conclusion is drawn that climate, land availability, economics of agricultural production and marketing, food demand, fertilizer shortage and water availability all combine to cast great doubt on the feasibility of producing grown organic matter for fuel, in competition with food, feed or fiber, on U.S. acreages. The feasibility of collecting residues may be nearer, but the competition for the residues for return to the soil or cellulosic production is formidable.

INTRODUCTION

The Experimental Fluid Mechanics Section, NASA Lewis Research Center, Cleveland, Ohio had underway, in 1973, a study of the feasibility of the conversion of biomass to liquid or gaseous fuels. A part of this study naturally involved the determination of the predicted availability, cost and characteristics of biomass feedstock. Municipal wastes and aquatic plants represent two possible sources and crops and trees grown on the land represent another possible source. In June 1973, the Ohio Agricultural Research and Development Center contracted to study "Grown Organic Matter as a Fuel Raw Material Source" as an input to this NASA study.

Some system syntheses of bioconversion schemes have been cited in this report, and others are known to exist. Some common faults with some of these studies accrue from the apparent circumstances that the authors understand systems analysis better than they understand crop production. This report may err in the opposite direction. But it is believed that it is realistic from the standpoint of water and land availability, crop production input problems and producer options based upon the market place. The factors considered in this report should therefore be given serious qualitative as well as quantitative consideration.

This analysis has attempted to uncover all of the substantiated information about dry matter yields of biomass, the inputs, length of growth period, temperature and water requirements and mechanization requirements of any species of plant, growing anywhere in the world, that might be a logical candidate for biomass production in the U.S. After this search was made the list was pared down because of one or more faults with each species with respect to its real potential for growth in the U.S. A few species were then analyzed in detail for feasibility of their production for a bioconversion feedstock.

It is believed that all of the varieties and species of land plants that are of possible importance in biomass production have been considered, along with their production potential and input requirements. Although species other than the 9 selected for detailed analysis may be logical candidates for biomass production, it is believed that none will come through the tests of suitability applied in this study with materially greater likelihood of practical bioconversion feedstock production. The field of practical possibilities for bioconversion feedstock production species has been reasonably encompassed in this study.

It has been the purpose of this study to define the problems inherent in any attempt to produce grown organic matter for conversion to fuel. Also, the approach has been to evaluate the economic and societal complications of such an attempt in terms of specific crops grown in specific areas under specific management practices, as seem realistic based upon the cumulative agricultural research knowledge of this research institution.

This study has differed materially from some other studies of biomass production. It has not assumed that conditions can be made favorable for maximum production at minimum input costs. Biomass production for any purpose - food, feed, fiber or fuel - always involves an appreciable degree of risk. Weather, disease, insects and poor management will always take their toll on any crop at some locations, part of the time. The techniques used in this study are those commonly used for decision-making in the face of risk, with the risk being represented by the best available statistical information on the probabilities of occurrence of various disadvantageous conditions of weather, disease, pests, etc.

Certain discrete sections of the Appendices are the individual work of persons who have taken part in this study but who are not necessarily responsible for the report as a whole.

MAIN TEXT

This report is essentially an analysis, without experimentation but with adequate information from the literature, of the possibility that the U.S. can and will spare enough productive capacity from the production of food, feed and fiber to enable the development of a synthetic fuel production industry using grown organic matter as a feedstock.

The model for this analysis is the model of the world's most productive system for the output of biomass for the food, feed and fiber needs of man - the U.S. agricultural production system. The analysis is made in the light of the fact that (1) no society has a more productive system model, (2) the U.S. has no better, workable model than present-day U.S. agriculture and (3) even if biomass production for conversion to fuel did not compete for land with the production of food, feed and fiber, it certainly must compete within the system for management capability, input resources and capital. Therefore, since a synthetic fuel industry based upon land-grown biomass feedstock would have to compete directly within the framework of an existing system, it would appear that the best way to analyze the feasibility of producing biomass for conversion to fuel is to consider each candidate species as just another possible agricultural crop to be grown by U.S. farmers.

The first part of this report delineates the requirements and limitations of growing biomass on the land areas of the United States, the cost and energy requirements of producing different crops, and the effects of fuel and fertilizer prices on crop prices. The second part of this report discusses the alternatives of whether fuel or food will be produced on the land. The third part considers the feasibility of using plant residues for fuel.

Part I. Biomass Production

An annotated bibliography has been prepared to assess and display the information in the scientific literature concerning the biomass production potential of various candidate species. This annotated bibliography is included as Appendix A to this report. It shows that there are no panaceas in biomass production. No exotic plant species were found to have high biomass production potential with minimum inputs. And none is expected to be found. Nine species of plants, which are high producers from various plant types such as grasses, cereals, root crops and trees, were selected for detailed analysis.

Yield responses to the following inputs were considered: crop management, nutrients, soil drainage, rainfall, temperature, and solar radiation. The crops considered were alfalfa, corn, kenaf, napier grass, pine, potatoes, sycamore, sugar beets, and wheat.

Crop management involves cultural practices such as seed bed preparation, fertilization, seeding rates, spraying schedules and cultivation. A comparison of these cultural practices (Table 1) indicates that potatoes require the greatest management input while pine or sycamore, once established, require the least. In evaluating the type of equipment needed for producing each crop (Table 2), it was found that the only specialized pieces of equipment are machines for planting and harvesting. All crops would require some tillage for seed bed preparation, weed control, and incorporation of fertilizer during plant establishment.

Nutrients (elements) required for plant growth are indicated in Table 3. Elemental composition varies slightly among different plant species. The major elements (carbon, oxygen, and hydrogen) found in the plant structure are obtained from the air and water. The remaining elements normally come from the soil. Of these, the primary nutrients (nitrogen, phosphorus and potassium) are the most important and are usually added to the soil during fertilization. Tables 4 and 5 give the composition and fertilizer requirements of several crops.

In a discussion of nutrient requirements for crop growth, the concept of "most limiting factor" becomes important. This concept states that the growth rate of a plant is restricted whenever a factor (such as a nutrient), necessary for growth, is not available. The implication of this concept is that maximum crop yields will require that adequate levels of soil fertility be maintained.

Although natural soil weathering processes ensure a release of essential elements sufficient to sustain plant growth, this release is seldom rapid enough to produce maximum biomass. Consequently, direct fertilization is necessary.

Soil drainage is an important factor for the production of high biomass yields. Schlaudt (1955), in discussing the drainage of forest lands, noted that loblolly pine trees in plantations in North Carolina yielded 16 times more wood on well-drained sites than on poorly-drained sites at the end of 16 years of growth.

Woods (1974) noted that kenaf can be grown on flat, poorly-drained soils in the Southeast, but the highest yields are obtained on well-drained soil. Woods also noted that young kenaf seedlings will not survive if flooded.

Schwab et al. (1972) noted that corn yields in Ohio were 1.4 times greater on well-drained soil than on poorly-drained soil, and the year-to-year variation (standard deviation) in yield was over twice as great on the poorly-drained soil. Schwab concluded that ensuring adequate drainage would increase average yields and reduce the frequency of low yields.

TABLE 1. Cultural Practices Used in Growing Crops

Alfalfa:	1st year Broadcast fertilizer, plow, disc twice, plant 13.4 kg seed/hm^2, spray with herbicide, harvest in July, spray with an insecticide, harvest in September. 2nd and 3rd years Broadcast fertilizer, harvest June 1-10, July 15-25, Sept. 10-15, spray with an insecticide after first harvest.
Corn:	(1) Broadcast fertilizer, plow (moldboard or chisel), disc twice plant 49-54,000 seeds/hm^2, band fertilize, spray with a herbicide, harvest after September. (2) Plant (no till planter), spray with a herbicide (contact herbicide + pre or post emergence herbicide), harvest after September.
Kenaf:	Plow (moldboard or chisel), disc twice, plant 9.0 kg seed/hm^2, spray with fungicide, cultivate, harvest after September.
Napier grass:	1st year Broadcast fertilizer, plow or disc twice, plant stem or root cuttings 61 cm apart in rows spaced 102 cm apart, cultivate twice for weed control or spray with a herbicide. 2nd thru 5th years Broadcast fertilizer in March and June, harvest every 60 days cutting 30 cm above ground.
Pines:	1st year Burn, plow or disc, fertilize, plant 3400 plants/hm^2, cultivate for weed control or spray with a herbicide. Harvest at the end or 20 years, replant.
Potatoes:	Cut large seed potatoes 5 to 10 days before planting, or use B size seed. Broadcast fertilizer, plow (moldboard), disc twice, plant about 1,450 kg of potato seed/hm^2 (2-man operation) and band fertilize, use a herbicide, spray every 10 days with fungicide sprays and insecticides, harvest, storage 279-283°K (42-50°F).
Sycamores:	1st year Plow or disc, broadcast fertilizer, plant 6900 cuttings (or seedlings)/hm^2, spray herbicide and cultivate for weed control. Harvest every 2 years by coppicing, replant every 10 years.
Sugar Beets:	Plow (moldboard, or chisel), disc or harrow twice, plant 99-148,000 seeds/hm^2, spray with a herbicide, cultivate three times, harvest.
Wheat:	(1) plow or disc, plant 112 kg/hm^2 and band fertilize, harvest.

TABLE 2. Equipment Required for the Production of Crops

Tractors, Plow(s), Discs, Harrow, Planter[a], Fertilizer Broadcaster, Sprayer, Harvester[a]

[a] The planter and harvester are specialized pieces of equipment which need to be designed for a specific crop.

TABLE 3. Average Concentration of Essential Elements in Whole Plants[a]

Element	Percent
Oxygen	45
Carbon	44
Hydrogen	6
Nitrogen	2
Phosphorus	0.5
Potassium	1.0
Calcium	0.6
Sulfur	0.4
Magnesium	0.3
Boron	0.005
Chlorine	0.015
Copper	0.001
Iron	0.020
Manganese	0.050
Molybdenum	0.0001
Zinc	0.0100
TOTAL	99.9011

[a] From Berg, 1973.

TABLE 4. Fraction of Major Elements Found in Main Parts of Plants Chosen for Biomass Production Evaluation

Crop	Plant Part	Percent of Whole[a]	N	P	K	Ca	References
			(kg nutrient/kg dry matter)				
ALFALFA:	Whole	100	.0350	.0054	.0282	.0147	Van Keuren 1973
CORN:	Kernels	40	.0142	.0033	.0037		Sayre 1948
	Cob	10	.0069	.0160	.0041		
	Stover	50	.0099	.0018	.0129		
	Whole	100	.0113	.0025	.0083		
KENAF:	Foliage	32	.0312		.0080	.0190	Clark 1969
	Stalk	40	.0083		.0080	.0070	
	Bark	28	.0021		.0090	.0090	
	Whole	100	.0139		.0083	.0114	
NAPIER GRASS:	Whole	100	.0096	.0041	.0131	.0060	Composition of Cereal Grains and Forages 1958
SLASH PINE: (5 yrs)	Bolewood	71	.0021	.0003	.0006	.0012	White 1970
	Tops	29	.0080	.0008	.0029	.0025	
	Whole	100	.0038	.0004	.0013	.0016	
POTATOES:	Tuber	71	.0155	.0025	.0171		Kunkel 1973
	Aerial	29	.0199	.0020	.0395		
	Whole	100	.0168	.0023	.0235		
SUGAR BEETS:	Roots	75	.0159	.0024	.0152	.0024	Hills 1974
	Tops	25	.0242	.0023	.0579	.0101	
	Whole	100	.0180	.0024	.0259	.0043	
SYCAMORE:	Whole[b]	100	.0073	.0012	.0039		Gerloff 1964
WHEAT:	Kernels	40	.0220	.0047	.0044		Handbook of Ohio Expt. 1957
	Straw	60	.0067	.0008	.0087		
	Whole	100	.0129	.0024	.0070		

[a] Dry Matter Basis.
[b] Based on composition of *Acer saccharum*.

TABLE 5. Fertilizer Requirements of Crops Adapted to Biomass Production[a].

Crop	Plant Part[b]	kg Fertilizer required/kg dry matter			
		N	P_2O_5	K_2O	CaO
Alfalfa	Whole[c]	None	.0123	.0340	.0207
Corn	Whole[c]	.0118	.0057	.0100	None
Kenaf	Whole[c]	.0139	.0050(est.)	.0100	.0161
	Stalk & Bark[d]	.0087	.0050	.0110	.0108
Napier Grass	Whole[c]	.0096	.0093	.0158	.0085
Slash Pine (5 yrs)	Whole[c]	.0038	.0009	.0016	.0023
Potatoes	Whole	.0168	.0053	.0283	None
Sugar Beets	Whole	.0180	.0054	.0312	.0061
Sycamore	Whole[c]	.0073	.0028	.0047	None
Wheat	Whole[c]	.0129	.0053	.0084	None

[a] Based on Table 4.
[b] Dry matter basis.
[c] Does not include roots. Assumes that nutrients required by roots of alfalfa corn, kenaf, napier grass, slash pine, sycamore and wheat are recovered from the preceding crop.
[d] If foliage is left in the field, an estimated 80% of the nitrogen is recovered through breakdown in the soil. All P_2O_5 and K_2O in the foliage is recovered.

In addition to benefiting plant growth, good drainage lengthens the growing season by permitting earlier tillage and planting and minimizes delays in the machine operations of tillage and harvesting due to wet areas in a field.

If so-called "marginal land" is to be used for the production of biomass, then soil drainage will be necessary. Otherwise, below-average yields, wide yearly yield variations and harvesting difficulties can be expected. Figure 1 indicates the location of the .994 Mm^2 (245.6 million acres) or 17% of the non-federal rural land which needs drainage (land with excess water). All nine crops considered for biomass production in this report would achieve their highest yields on well-drained lands. Alfalfa, in particular, requires very well-drained land to maintain stands and high yield levels.

The water requirements of a crop are sizable with a range of 50-76 cm (20-30 inches) needed during the growing season. An exception is wheat which requires only 30-38 cm (12-15 inches) of water. Water requirements are met by soil moisture reserves at the start of the season plus rainfall during the season (excluding the possibility of irrigation). Figure 2 indicates normal rainfall received by different regions of the continental United States during the crop-growing season (April 1 through September 30). Considering the total land area, it is estimated that 31% has less than 25 cm (10 inches) of water per growing season, 28% has between 25 and 50 cm (10 and 20 inches) and 41% has an excess of 51 cm (20 inches) per season. However, the normal rainfall of an area does not necessarily indicate the amount of water which is available for crop growth because infiltration, soil water storage capacity, and evaporation rates will vary in different areas. Most of the land area receiving adequate rainfall lies east of the Mississippi River in the Northeast, Lake, Corn Belt, Appalachian, Southeast and Delta States (See Figure 3). This area contains approximately 2.727 Mm^2 (673.5 million acres) of non-federal rural land of which 0.073 Mm^2 (19.1 million acres) have no conservation problems, 1.223 Mm^2 (302.2 million acres) have erosion hazards, 0.830 Mm^2 (205.1 million acres) have excess water and 0.592 Mm^2 (146.3 million acres) have unfavorable soil.

When considering water availability, it is important to recognize that areas of the country which have wide fluctuations in rainfall will produce limited biomass without irrigation. All areas of the Western United States, other than the Pacific Coast Region, have large fluctuations in rainfall.

Temperature. The length of the growing season (Figure 4) is usually defined as the number of days between the average dates of the last spring frost and the first fall frost. A frost-free season of less than 125 days limits most annual corps. For corn production, a frost-free season of about 150 days is considered necessary for maximum yields while kenaf requires 220-250 frost-free days (Killinger, 1974).

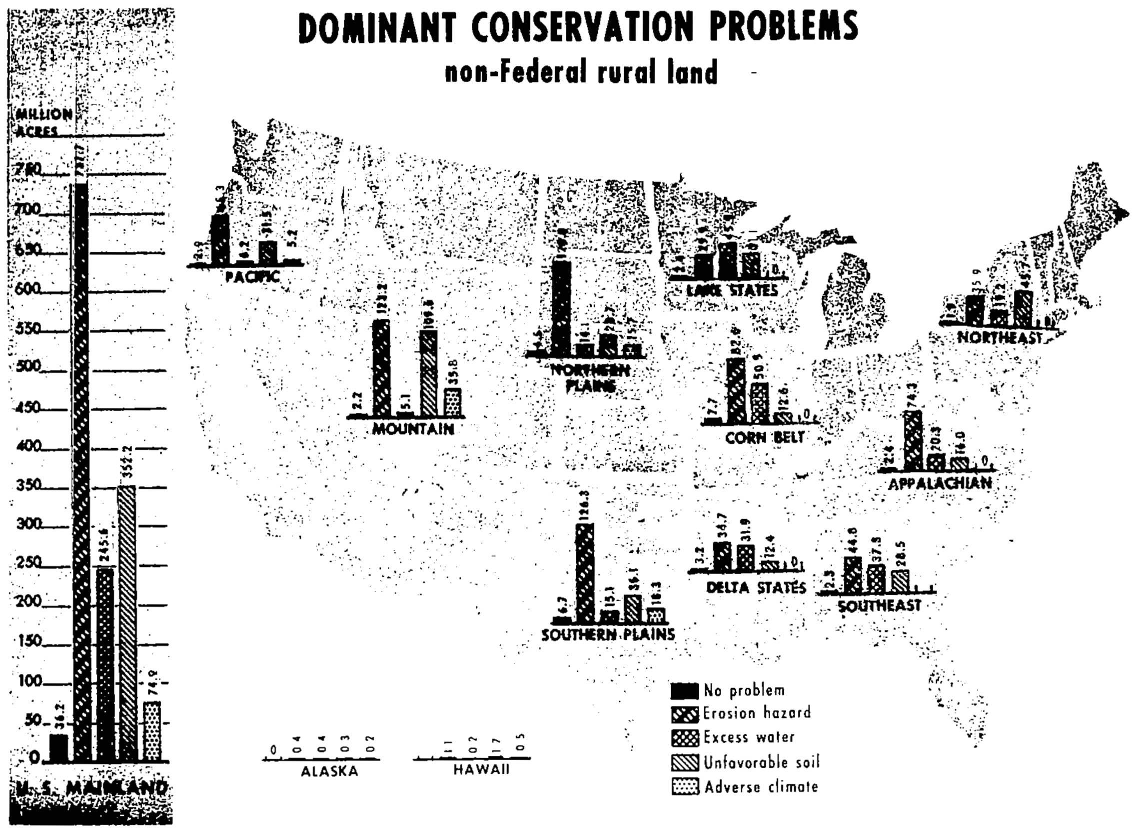


Fig. 1. Land acreages associated with conservation problems of non-federal rural land in the United States. (From USDA, Misc. Publ. No. 971). 1965.

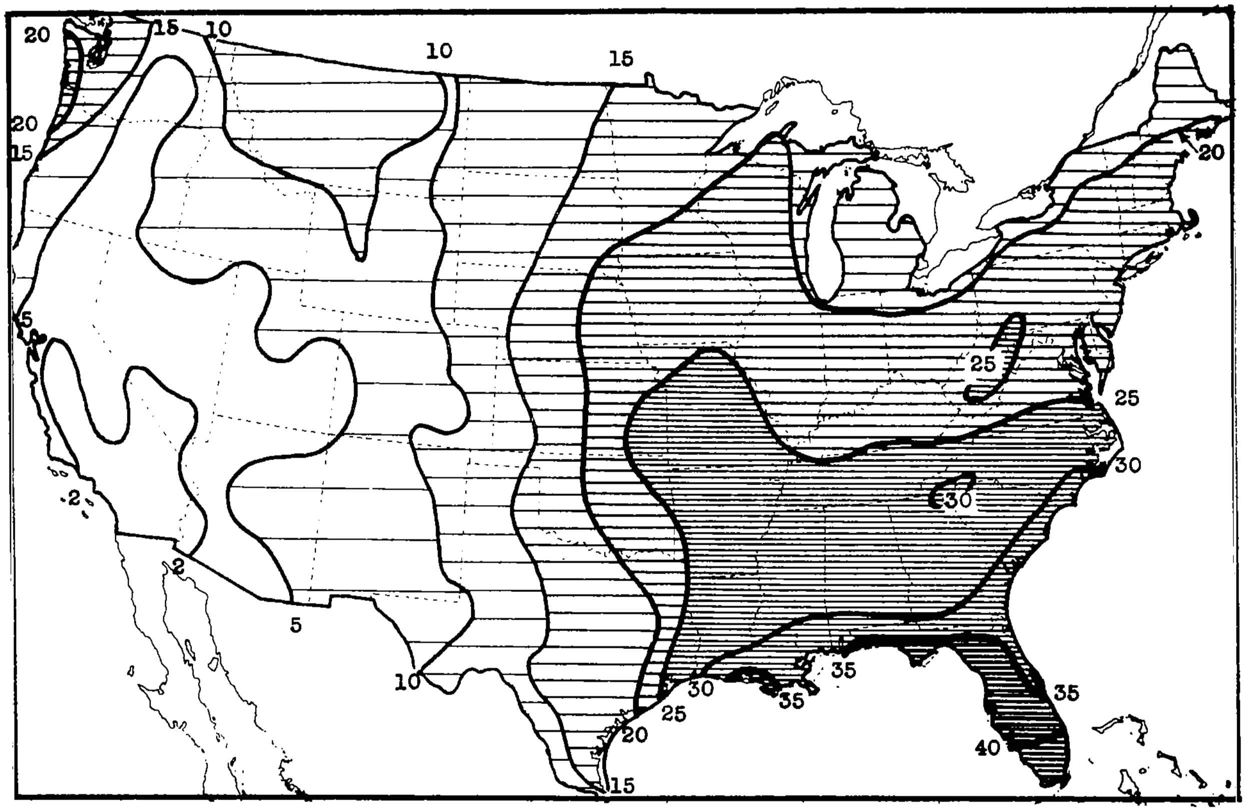


Fig. 2. Normal precipitation (in.) during the crop-growing season, April to September, inclusive. (From Visher, 1954).

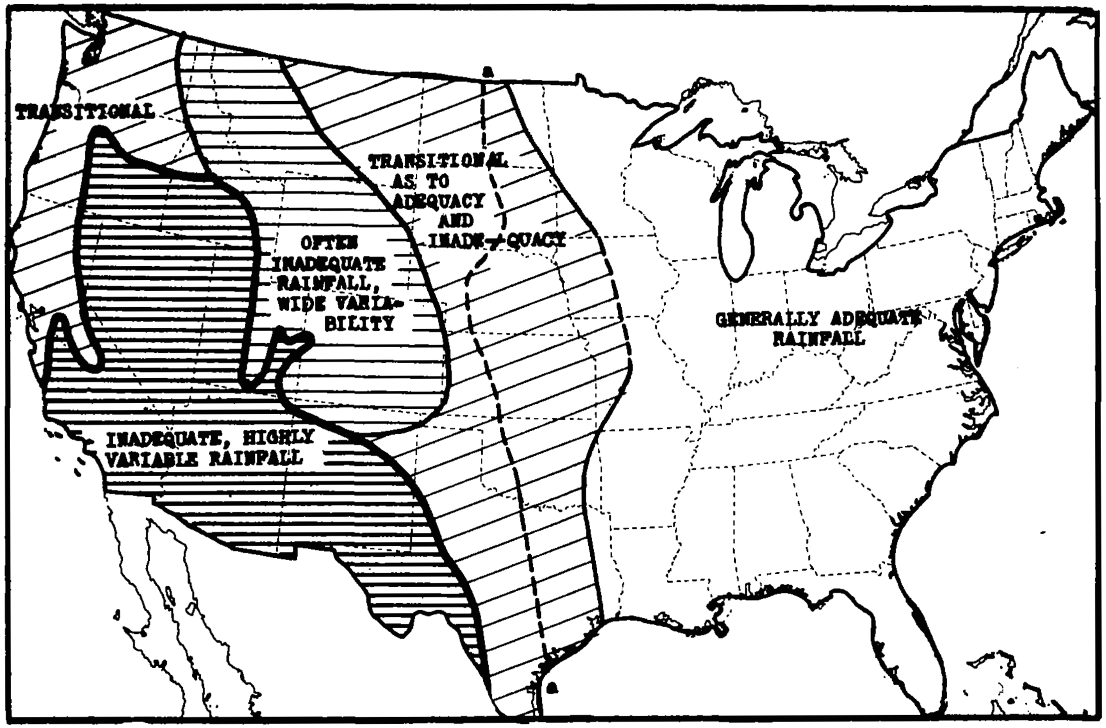


Fig. 3. Precipitation regions based on precipitation variability. (From Visher, 1954).

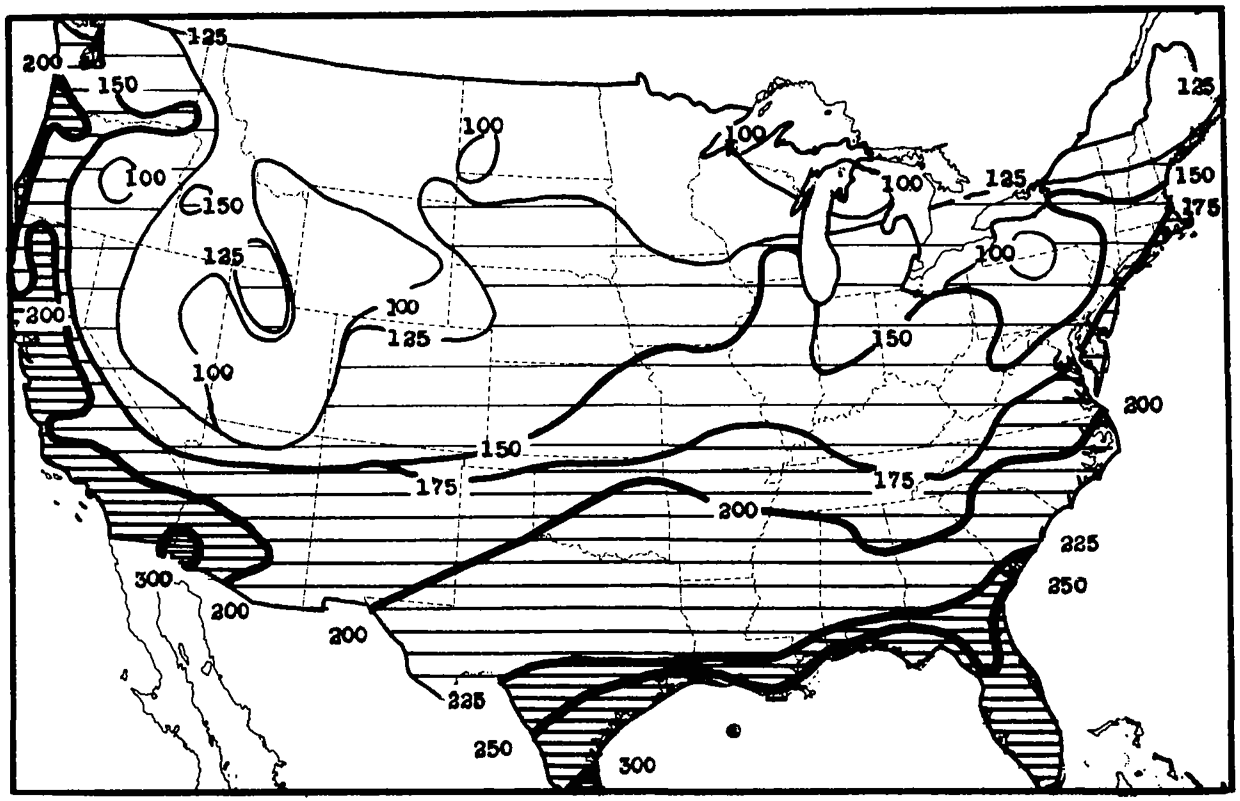


Fig. 4. The frost-free season was longer than here shown (days) in nine-tenths of the years, 1899-1938. (From Visher, 1954).

Also, favorable growth of most crops requires temperatures between 289 and 305°K (60 and 90°F). Below 289°K (60°F), a cool weather crop such as wheat will show favorable growth rates while corn, kenaf, or napier grass will have low growth rates. At sustained temperatures above 305°K (90°F) the growth rate of most crops is greatly reduced. Figure 5 shows the average number of days above 305°K (90°F) for different regions of the country. For the Southern United States, high summer temperatures for 60 or more days would reduce these states' potential for biomass production.

Solar Radiation is the energy source required for crop production. The energy available for conversion to biomass is a function of duration and intensity of sunlight. These factors are in turn affected by latitude, day of the year and cloudiness. Figure 6 shows the total amount of solar radiation received during the year for the different regions of the country. Western states such as New Mexico show the highest levels. However, these states are also the ones with low rainfall during the growing season.

When considering crop response to solar radiation, each plant has its own efficiency for converting absorbed solar energy to plant carbohydrates. There are two classes of plants based on this concept, C_3 and C_4 plants. (See Appendix B). The terms C_3 and C_4 refer to different biochemical pathways internal to the plant. Figure 7 shows the photosynthetic response of several plants. The photosynthate produced (in terms of CO_2 used) is plotted against light intensity. Maize (corn), a C_4 plant (the others are all C_3 plants), is the most efficient.

A plant must absorb the solar energy which it converts to stored chemical energy. Absorption by the crop canopy is a function of the structure of the crop (its leaf arrangement) and the total leaf area per unit area of land surface (row spacing and plant spacing). However, once the leaf mass has developed to provide complete ground cover, the absorptivity is fixed and crop yield is a function of solar radiation levels and conversion efficiencies (other factors not limiting).

Discussion. Maximum biomass production requires that a crop be adapted to the regional climatic conditions of rainfall, temperature, and solar radiation. On the basis of knowledge gained from field experimentation about requirements for crop growth, the United States has been divided into specific agricultural regions (Figure 8). A map of these regions indicates locations in which particular crops are most likely to produce maximum yields.

Of the nine crops which were selected for detailed evaluation, alfalfa, potatoes, and sugar beets would be expected to produce best in the hay and dairy regions of the Northeast and Lake States. These regions have a growing season of less than 120 days and moisture levels of 50-76 cm of rainfall per growing season. Maximum corn performance would be expected in the Corn Belt and Appalachian States where the growing season is 125-175 days and rainfall is

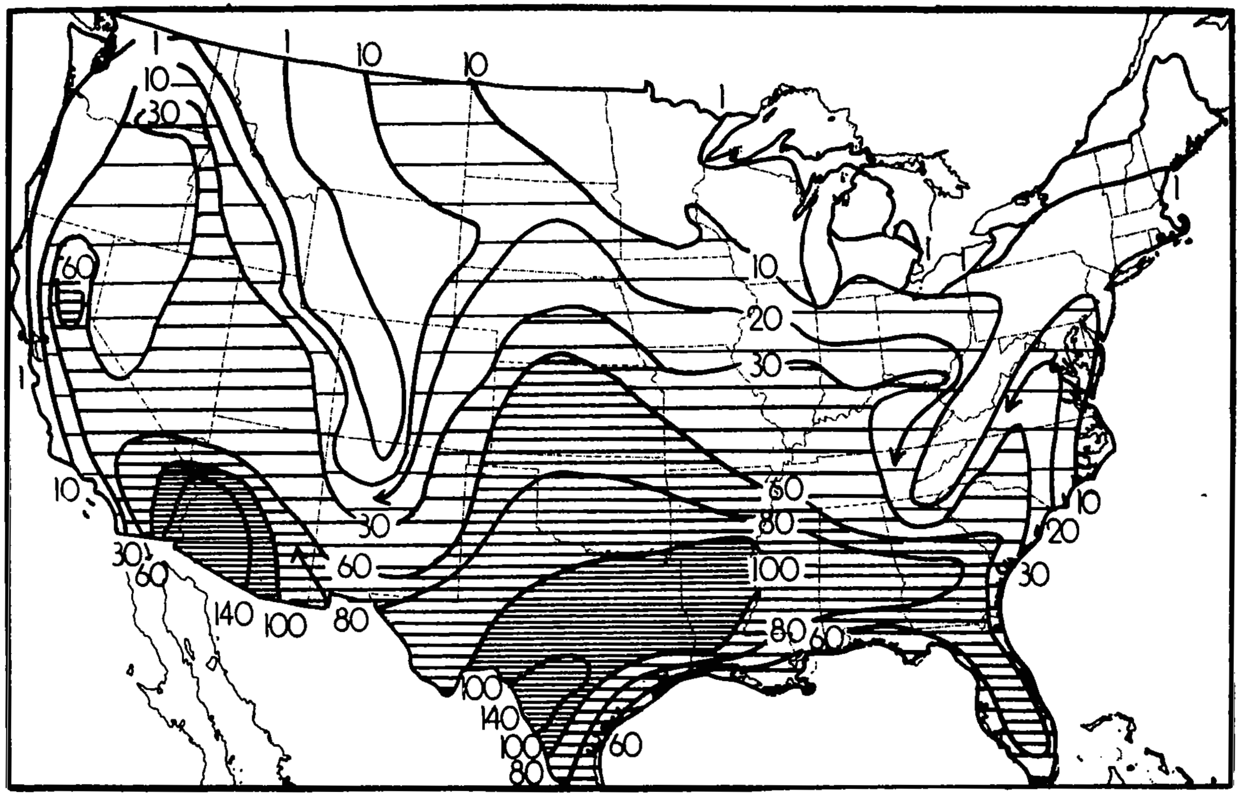
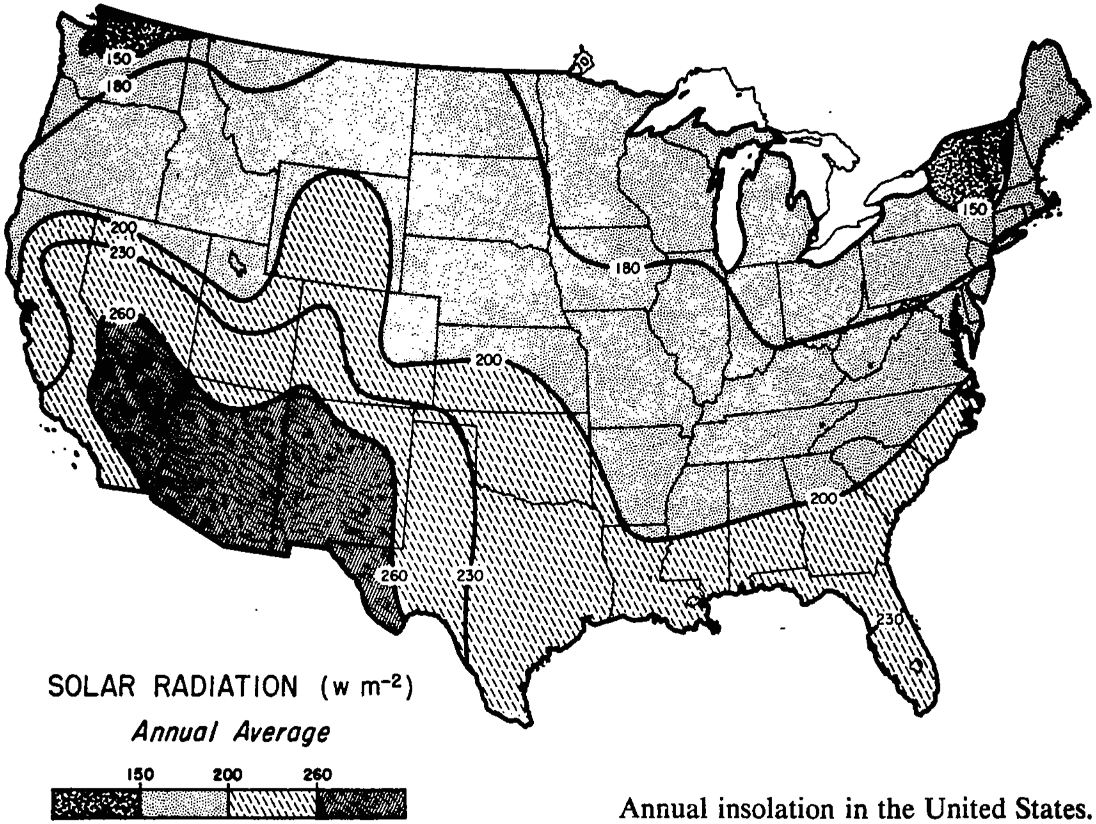


Fig. 5. Normal annual number of days with maximum temperature of 90^{o}F or higher. (From Visher, 1954).



Annual insolation in the United States.

Fig. 6. Annual insolation in the United States. (From Calvin, 1974).

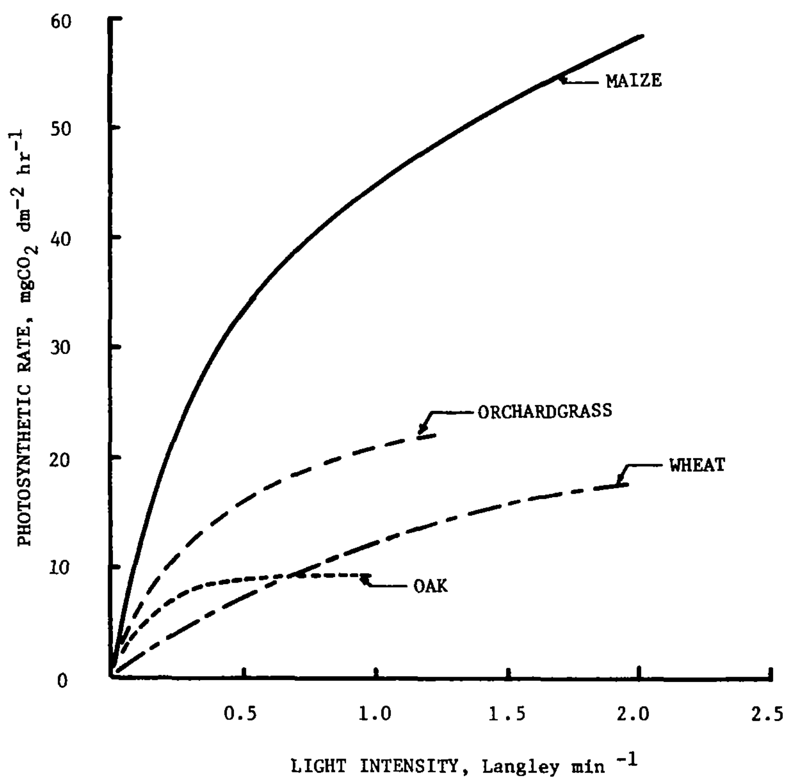


Fig. 7. The effect of light intensity on photosynthetic rates.

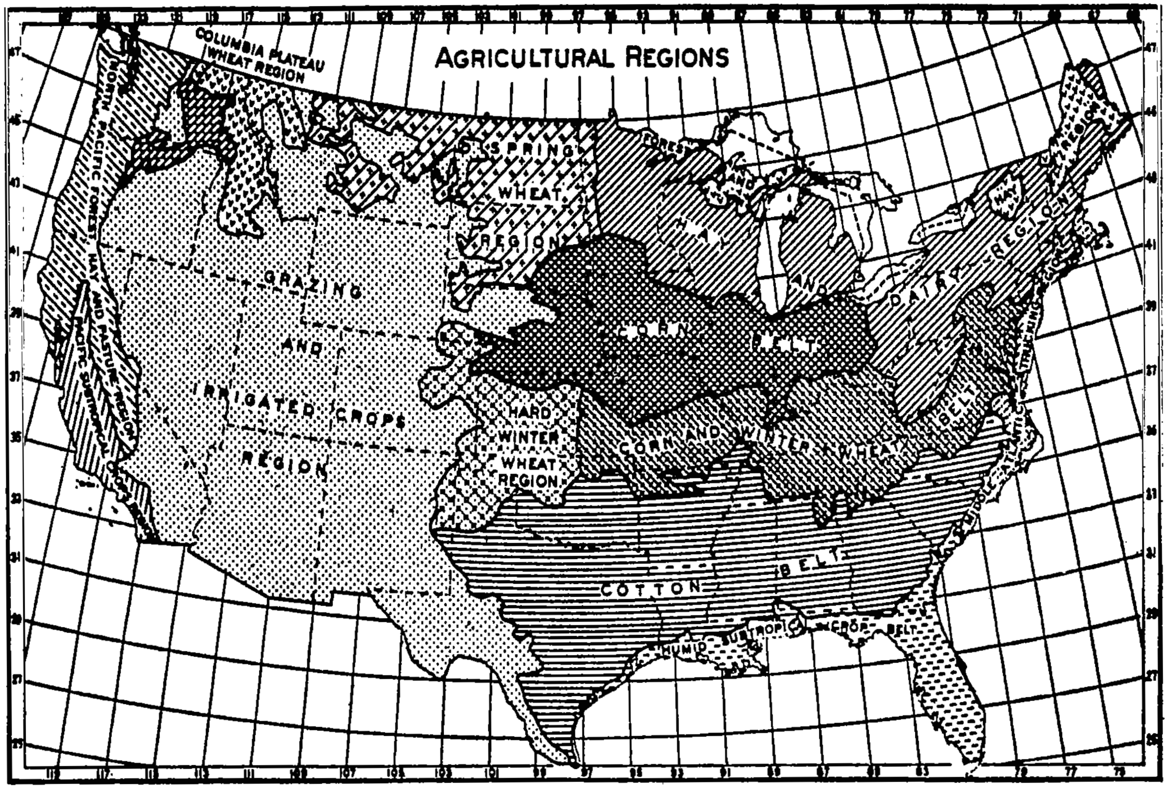


Fig. 8. Agricultural regions of the United States. (From Visher, 1954).

50-76 cm per growing season. Kenaf would yield best in the Southeast, Delta and Southern Plains States where the growing season is over 200 days and rainfall is over 50 cm. Napier grass would be limited to the Humid Subtropical Crop Belt of the Southeastern States. In the semi-arid regions of the west, such as the Northern Plains States where rainfall is 25 to 50 cm per growing season and the number of frost-free days is less than 175, wheat would be the best-yielding crop. All regions of the Eastern United States would be favorable for sycamore production, while pines would be restricted to the Delta and Southeastern States (Figure 9). The Mountain States would not lend themselves to intensive biomass production without irrigation. The climatically adapted crops for the Pacific States would be alfalfa, sugar beets, potatoes and pine.

Yields of Selected Crops. Of the factors discussed under "Yield Responses to Input", man does not exercise much control over genetic potential and solar radiation. Through hybridization and selection, man has been developing high-yielding crops (an example of predicted genetic gains through various breeding techniques can be seed in Appendix C), but man has not created a new superplant capable of converting solar radiation into plant biomass with more efficiency than C4 plant species such as corn and other grasses. With all of man's abilities to forecast weather, he can do little to increase the level of solar radiation impinging on the photosynthetic sites of the plant world. Consideration of these two facts leads to the following postulates on plant yields:

(1) Under an optimum environment of nutrient availability and disease control, the yield of a crop reflects the genetic potential of the crop for a given soil moisture, temperature and solar radiation level.

(2) Under an optimum environment of nutrient availability and disease control, the year-to-year variation in plant yield is determined by soil moisture, temperature and solar radiation levels during the growing season.

(Note: Plant yield is a random variable since solar radiation level and soil moisture level are random variables).

These postulates will be used to determine optimum fertilization levels for crops and to calculate expected yields.

The yield potentials of many crops have been studied over the years and are indicated in the literature. Table 6 is a summary of yield data for nine crops grown with good management practices. These yields do not reflect optimum growing conditions in most cases, since water availability and air temperatures were not controlled. However, they do represent actual yields when nutrients in the soil are not lacking and disease is not a problem. These yields are the expected biomass production levels achieved without irrigation[1].

[1] In this study, irrigation was excluded because of its high energy requirements and the lack of water resources in many regions of the U.S.

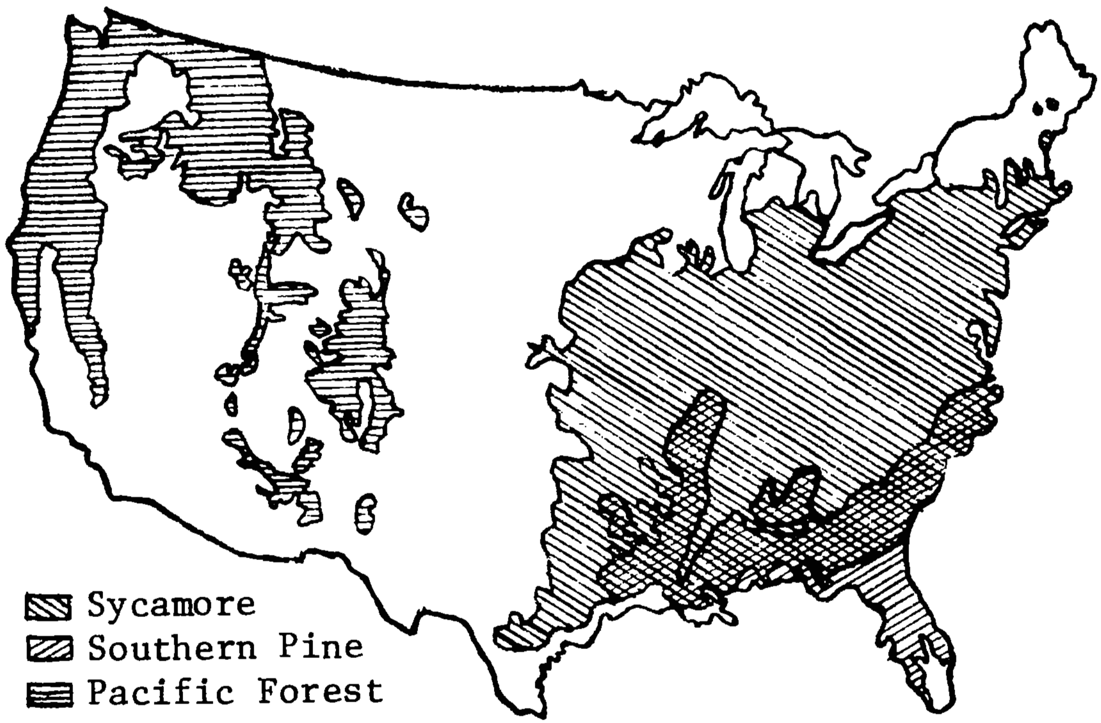


Fig. 9. Selected forest regions of the United States. (Adapted from Visher, 1954 and Fowells, 1965).

TABLE 6. Annual Biomass Yields of Nine Selected Crops.

Crop	Region[a]	n[b]	Plant Part	Yield[c], t/hm² $\bar{x}$	S	Plant Part	Yield, t/hm² $\bar{x}$	S	Reference[d]
ALFALFA	3	4				Whole	13.66	3.05	74
	3	4				Whole	13.66	3.09	9, 58, 68
	2	3				Whole	13.28	----	59
CORN	3	5	Kernels	7.80	.78	Whole	19.50	1.79	83
	3	4	Kernels	6.52	.87	Whole	16.40	2.20	1
	6	4	Kernels	5.62	1.28	Whole	14.00	3.20	23, 24, 36
	2	5	Kernels	8.04	0.36	Whole	16.10	0.72	46, 39
KENAF	5[f]	5	Stem	12.60	1.52	Whole	18.52	2.23	34
	3[g]	3	Aerial	20.83	4.26	Whole	20.83	4.26	80
	6	6	Stem	19.85	3.24	Whole	29.19	4.76	81
NAPIER GRASS	-	1				Whole	60.65	4.49	11
	6[h]	4				Whole	9.98	1.43	6
PINE	7[i]		Bolewood	10.30	1.50	Whole	14.51	2.11	48
	7[j]		Bolewood	6.87	1.00	Whole	10.92	1.57	47
POTATOES	1	2	Tuber	7.70	0.34	Whole	10.85	0.48	52, 53
	2	4	Tuber	6.50	0.85	Whole	9.15	1.20	76
	9		Tuber	7.84	0.43	Whole	11.04	0.61	50
SUGAR BEETS	4[f]	2	Roots	12.56	0.06	Whole	16.72	0.08	33
	10[f]	2	Roots	11.48	1.71	Whole	15.29	2.28	35
	3	3	Roots	10.49	0.43	Whole	14.00	0.57	44
SYCAMORE	6[k]	1	Aerial	16.35	2.50	Whole	16.35	2.50	66
WHEAT	3	5	Kernels	2.98	0.49	Whole	7.45	1.23	83
	4	3	Kernels	2.53	0.76	Whole	6.33	1.90	12, 13, 77
	6	3	Kernels	3.90	0.54	Whole	9.75	1.35	20, 21, 22

SEE FOOTNOTES ON FOLLOWING PAGE.

$\bar{x}$ = Mean Yield   S = One standard deviation of Yield

TABLE 6. Annual Biomass Yields of Crops. Continued.

Footnotes.

a Regions: 1 - Northeast, 2 - Lake States, 3 - Corn Belt, 4 - Northern Plains, 5 - Appalachian, 6 - Southeast, 7 - Delta, 8 - Southern, 9 - Mountain, 10 - Pacific.

b n = number of years of record

c Dry matter basis.

d Numbers refer to references at end of report.

e Ratio of plant constituents was .50 grain, and .50 stalk and cob (Keeney, 1967).

f Irrigation used in growing crop.

g Post frost - contains some leafy material.

h Low levels of fertilization used during test.

i Slash pine, site index 96, based on a 19-year rotation, 2600 trees/hm^2, sp. gr. = .67.

j Loblolly pine, site index 90, based on a 17-year rotation, 2600 trees/hm^2, sp. gr. = .63.

k Based on coppicing every two years. Standard deviation of yield uncertain.

Napier grass, kenaf, corn and sycamore had yearly average yields of over 15 t/hm^2. (The yields of napier grass in Florida were low because of inadequate soil fertility). These yields were for crops grown in well-drained, highly fertile soils without irrigation in areas which received 50 cm of rainfall during the growing season. Alfalfa, potatoes, slash pine, sugar beets, and wheat had average yearly yields of 13.66, 9.15, 14.51, 14.00 and 9.75 t/hm^2 respectively.

However, crop yield is only one aspect to be considered when selecting a crop for biomass production. The cost of fertilizer, equipment, and labor is also important.

Fertilizing for Optimum Yields. The fertilization of crops considers the effect of over-fertilization as well as under-fertilization. For phosphorus, potash, and minor elements, the amount not removed by the plant during the growing season will be available to the crop in future years. For this reason, most agronomists recommend establishing soil fertility levels (P and K) somewhat higher than those required for maximum production to ensure non-limiting fertility. Once a high soil-fertility level is reached, nutrients (other than nitrogen) should be applied at levels corresponding to the amount of nutrients removed from the soil by a harvested crop.

The element nitrogen (nitrate form) is highly mobile in the soil and is lost through leaching and denitrification. If applied at excessively high levels, a relatively large proportion of nitrogen will be lost during years when crop yields are low. However, if applied at low levels, nitrogen will limit crop growth during the years when climatic factors favor high yields. Considering crop yield potential and nitrogen loss, Keener (Appendix D) has obtained a prediction of the optimum fertilization rate for a desired yield level which optimizes the farmer's expected net income. The optimum fertilization level, y_f^*, is:

$$F\,(y_f^*) = \frac{P - \sum_{i=1}^{N} c_i r_i - c_n r_n}{P - \sum_{i=1}^{N} c_i r_i} \qquad (1)$$

where $F(y_f^*) = \int_0^{y_f^*} f(y)dy$

$f(y)$ = probability density function for crop yield (y, $t/hm^2{\cdot}yr$) when nutrients are not lacking and only climatic factors of solar radiation, temperature, and rainfall control crop yield each year.

P	=	price received for crop, \$/t.
c_i	=	unit price of nutrient i, \$/t of i
r_i	=	amount of nutrient i required to grow the crop, t/t
c_n	=	unit price of nitrogen, \$/t
r_n	=	amount of nitrogen required to grow the crop, t/t.

Using 1974 cost data for fertilizer and the yield data given in Table 6, the optimum nitrogen levels at which to fertilize certain crops were estimated and are presented in Table 7. In addition, these tables include expected crop yield levels and requirements for P_2O_5 and K_2O.

Costs and Energy Requirements of Producing Biomass. Because of lesser biomass production potential, potatoes, sugar beets and wheat were dropped from further analysis. To estimate the cost of producing alfalfa, corn, kenaf, napier grass, slash pine and sycamore, model enterprises of 162 hm^2 were considered. Labor and equipment requirements, and material input requirements (fuel, fertilizer, insecticides and herbicides) were estimated and used to compute costs and energy requirements of biomass production (Appendix E).

Napier grass had the lowest cost of production, \$18.22/t of dry biomass. Alfalfa had the highest cost of \$41.09/t of dry biomass. Production costs of the other crops ranged from \$27.75 to \$32.06/t of dry biomass. Included in the production costs were a \$98.80/hm^2 land charge and a \$98.80/hm^2 return to management. Table 8 gives a summary of the production costs for the six crops.

In terms of energy, pine had the lowest production requirement of 613 MJ/t (146,500 kcal/t) of dry biomass produced while corn had the highest of 1287 MJ/t (307,860 kcal/t). Production costs of the other crops ranged from 889-1177 MJ/t (212,660 - 281,400 kcal/t) of dry biomass. A breakdown of energy requirements for each crop is given in Table 9. Fertilizer, fuel and equipment manufacture were the inputs to crop production which required the most fossil energy, accounting for 96 to 99% of the total fossil energy consumed.

The rate of energy return for a crop is given by the energy ratio, i.e. the energy in crop/energy used to produce the crop (Table 9). This ratio measures the potential of a crop, raised in a specified culture, for increasing stored energy supplies through the production of biomass. The energy ratio for pine, which has low fertilizer requirements and a relatively long harvest interval, is 25.3. This means that for each joule of energy put into the system, 25.3 J of energy are produced and stored in the form of biomass.

It may be noted that the energy ratios in Table 9 are much higher than some that have been published elsewhere. These ratios differ from other published ratios for at least 3 possible reasons as follows:

1. The other, lower ratios have been calculated using statistical inputs of energy, i.e., average electrical use per area determined by divid-

TABLE 7. Optimum Fertilizer Rates for Crop Levels Sought.

Crop[a]	Location		Yield Levels Sought[b] Biomass ($t/hm^2 \cdot yr$)	Expected Yield[c] ($t/hm^2 \cdot yr$)	($kg/hm^2 \cdot yr$)		
	Region	State			N	P_2O_5	K_2O
Alfalfa, whole	2	Wisconsin	13.28	13.28	--	163	451
	3	Ohio	13.66	13.66	--	168	464
Corn, whole	3	Ohio	20.80	19.30	235	110	193
	3	Iowa	18.00	16.10	203	92	161
	6	Georgia	16.40	13.60	185	78	136
Kenaf, stems	3	Indiana	17.00	13.90	148	70	153
	5	Maryland	14.10	12.50	123	62	137
	6	Florida	23.00	19.50	200	98	215
Napier Grass, whole	6	Puerto Rico	69.81	60.62	670	564	957
Slash pine, whole	6	Louisiana	18.40	14.49	70	13	23
Sycamore, whole	6	Georgia	19.12	16.15	140	45	76

[a]Wheat, sugar beets and potatoes were not included in this table because of low biomass yields Alfalfa was included because it requires no N fertilizer. Slash pine was included because of low nutrient requirements and long cycle time.

[b]Yield level for which N fertilizer should be applied in order to optimize expected net income. Assumes the following prices: biomass at \$10/t, N at \$.083/kg, P_2O_5 at \$.073/kg and K_2O at \$.032/kg. Bulk prices from U.S.S. Agricultural Chemicals, 1974.

[c]Yields averaged over several years. Accounts for yield variations due to varying rainfall and solar radiation levels.

TABLE 8. The Cost of Producing Crops[a].

Crop	Cycle Time (yrs)	Crop Yield[b] ($t/hm^2 \cdot yr$)	Return on Investment ($\$/hm^2 \cdot yr$)	Land ($\$/hm^2 \cdot yr$)	Operating Cost ($\$/hm^2 \cdot yr$)	Cost Per tonne
Alfalfa	3	12.1	$98.80	$98.80	$401.46	$41.09
Corn	1	19.3	98.80	98.80	363.32	29.06
Kenaf	1	19.5	98.80	98.80	343.51	27.75
Napier Grass	3	50.5	98.80	98.80	722.73	18.22
Slash Pine	20	14.5	98.80	98.80	267.56	32.06
Sycamore	10	16.2	98.80	98.80	303.41	31.00

[a] See Appendix E.
[b] Dry matter basis.

TABLE 9. The Energy Requirements for Crop Production[a].

Crop	Equipment	Seed	Labor	Chemicals	Fuel	Fertilizer	Total	Energy Ratio[b] (J/J)
	MJ/t							
ALFALFA	135.4	11.7	1.0	37.5	309.9	604.7	1100.2	14.1
CORN	91.5	6.4	0.4	23.6	159.3	1006.2	1287.4	12.0
KENAF	90.5	11.4	0.4	23.3	158.4	884.4	1168.6	13.3
NAPIER GRASS	32.6	11.9	0.3	3.0	99.8	1029.2	1176.8	13.1
SLASH PINE	77.7	3.1	0.7	1.6	175.8	353.9	612.7	25.3
SYCAMORE	133.0	4.3	0.3	2.8	95.4	652.9	888.7	17.4

[a] See Appendix E.
[b] Energy in crop/energy used to produce crop; based on 15500 MJ/t of photosynthetic dry matter.

ing the total electrical usage in agriculture by the area in crop production. Ratios in this report are calculated by using, wherever possible, actual input levels corresponding to the desired output yields as reported by agricultural experimenters.

2. Other, lower ratios, reflect average input conditions, where management is also apt to be average and one (or more) vital input is supplied in suboptimal amounts, resulting in yield limitation in spite of high levels of other inputs. Ratios in this report reflect optimum input conditions where all input levels are to assure high yields, on the basis of best experimental evidence.
3. Other published ratios may include only the energy output represented by grain or other readily useable plant parts. In this report, the energy output includes all of the above-ground biomass produced.

Before the overall efficiency of fuel production from biomass can be estimated, transportation costs from production site, efficiency of biomass conversion to a suitable energy form, and transportation of the energy to the consumer must be included.

The Effect of Fuel and Fertilizer Costs on the Cost of Producing Biomass. In considering the production of fuel from biomass, it is necessary to know the cost of the biomass. But it is equally important to know the cost of fuel when calculating the cost of biomass.

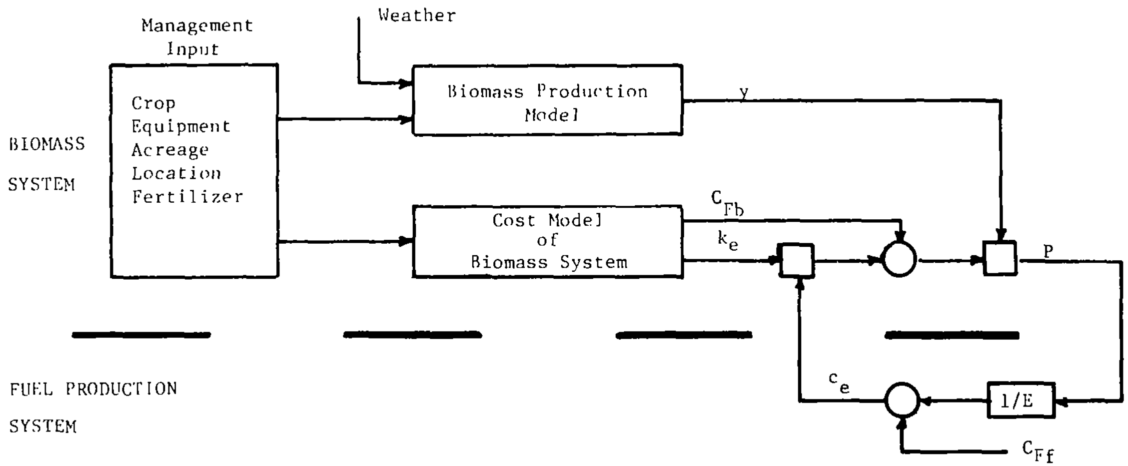
Direct Method: Figure 10 depicts a simplified production cost model of a biomass system and shows the feedback loop (or circular nature) of crop prices and fuel prices.

The top half of Figure 10 is equivalent to the equation:

$$P = \frac{C_{Fb} + k_e c_e}{y} \qquad (2)$$

where P = cost of producing biomass, \$/t.
C_{Fb} = fixed cost of biomass, $\$/hm^2 \cdot yr$.
(Costs assumed to be independent of the immediate cost of energy)
k_e = energy equivalent used in producing biomass, $J/hm^2 \cdot yr$
c_e = energy equivalent cost, \$/J
and y = yield level of crop for a given year, $t/hm^2 \cdot yr$

Since yield y is a random variable, the average annual yield for a given fertilization level, $\bar{y}$, will be used. Substitution of $\bar{y}$ into equation (2) gives:



y - yield, $t/hm^2 \cdot yr$
C_{Fb} - fixed cost of biomass, $\$/hm^2 \cdot yr$*
k_e - energy equivalent used in biomass, $J/hm^2 \cdot yr$*
P - cost of producing biomass, $/t
E - efficiency of fuel production, J/t
C_{Ff} - fixed cost of fuel production, $/J
c_e - fuel cost, $/J

* Costs assumed to be independent of the immediate cost of energy

$$P = \frac{C_{Fb} + k_e c_e}{\bar{y}} \tag{3}$$

Estimates of C_{Fb}, k_e and $\bar{y}$ for various crops have been calculated from the data in Appendix E, and are given in Table 10. With these data it is possible to estimate the theoretical effect of fuel price increases on crop production cost (assuming that costs of production other than the fuel used will not change as fuel costs change).

The bottom half of Figure 10 (the feedback loop) depicts the cost of producing fuel from biomass. It is equivalent to the equation:

$$c_e = (C_{Ff} + P/E) \tag{4}$$

where c_e = energy equivalent cost, \$/J
C_{Ff} = fixed cost of fuel production, \$/J
and E = efficiency of fuel production, J/t

Substitution of equation (4) into (3) and solving for P' (steady state price of biomass) gives:

$$P' = \frac{C_{Fb} + k_e C_{Ff}}{\bar{y} - k_e/E} \tag{5}$$

Using data of Graham (1974), estimates of steady state costs of fuel from biomass were found to vary from \$2.77/GJ (\$0.37/gal) to \$6.22/GJ (\$0.84/gal). The lowest cost was for napier grass while the highest cost incurred was for alfalfa. These results were based upon an energy conversion efficiency of 50% (Table 11). It should be remembered that equation 5 has fixed cost and energy cost components. Crops do not rank the same in \$/GJ in Table 11 as they do in GJ/t in Table 10 due to the differences in fixed costs per ton of biomass production.

TABLE 10. Cost Parameters Used in Estimating Biomass Production Cost[a].

Crop	Fixed Cost, C_{Fb} \$/hm$^2\cdot$yr	Energy Required, k_e GJ/hm$^2\cdot$yr	Expected Yield, $\overline{y}$ t/hm$^2\cdot$yr	$k_e/\overline{y}$ GJ/t	Rank
Alfalfa	459.00	13.36	12.1	1.10	(3)
Corn	487.00	24.85	19.3	1.29	(6)
Kenaf	472.00	22.79	19.5	1.17	(4)
Napier Grass	743.00	59.73	50.5	1.18	(5)
Pine	439.00	8.89	14.5	0.61	(1)
Sycamore	458.00	14.35	16.2	0.88	(2)

[a] Biomass production cost = (C_{Fb} + k_e* cost of energy)/$\overline{y}$.

TABLE 11. Steady State Price of Biomass and Fuel, 50% Conversion Efficiency[a].

Crop	P' ($/t)	c_e' ($/GJ)	Rank
Alfalfa	$44.81	$6.22 ($0.84/gal)	(6)
Corn	30.70	4.40 ($0.59/gal)	(3)
Kenaf	28.93	4.18 ($0.56/gal)	(2)
Napier Grass	18.03	2.77 ($0.37/gal)	(1)
Pine	34.35	4.88 ($0.66/gal)	(5)
Sycamore	31.95	4.57 ($0.61/gal)	(4)

[a] $E = 7.74$ GJ/t, $C_{Ff} = \$0.44$/GJ.

$P' = (C_{Fb} + k_e C_{Ff}) / (\overline{y} - k_e/E)$

$c_e' = C_{Ff} + P'/E$.

Since napier grass can be grown in only a limited region of the United States (Southern Florida), its potential as a biomass source is restricted. Of the remaining crops, kenaf and corn would be the lowest cost sources of biomass and would be adaptable to large areas of the United States. Their use would mean a minimum fuel production cost of \$4.18/GJ at today's biomass production cost and an energy conversion efficiency of 50 percent.

Statistical Method: Another way to determine the effect of fuel prices on the cost of producing biomass is to use recent data. Based on fuel and nitrogen fertilizer costs for 1973, the cost of producing corn biomass was calculated to be \$26.00/t. Using 1974 data, the production cost was \$28.80/t (Table 8). From 1973 to 1974, energy costs increased \$1.13/GJ (\$4.73/10^6 kcal). This data is plotted in Figure 11.

From equation (3) it follows that $\Delta P/\Delta c_e$[1] should equal $(\partial C_{Fb}/\partial c_e)/\bar{y} + k_e/\bar{y}$ when k_e and $\bar{y}$ are constant. If C_{Fb} is independent of c_e (as was assumed in the analysis, Table 10), $\partial C_{Fb}/\partial c_e$ would be zero and $\Delta P/\Delta c_e$ would equal $k_e/\bar{y}$. However, the slope of the line (Fig. 11) connecting the 1973 fuel cost - nitrogen cost intersection with the 1974 fuel cost - nitrogen cost intersection shows a value of 3.14 GJ/t. Thus, the cost of nitrogen in fertilizer had, in one year, reacted to the increased cost of energy as though an additional 3.14-1.29 = 1.85 GJ/t of energy had been used in the nitrogen fertilizer. Such is not the case. What is indicated is the amplification effect of the rising cost of fuel as it drives up the cost of almost everything - labor, return to management, transportation, etc. - which had previously been included in the $C_{Fb}/\bar{y}$ term as fixed costs. Thus, as fuel costs increased, the supposedly fixed costs, as well as the energy costs, increased. This means that the estimates of cost for fuel made from biomass given in Table 11 are probably lower bounds.

On this basis, the new steady-state price of biomass and fuel, assuming 50% conversion, would be \$35.05/t and \$4.97/GJ (\$0.66/gal), respectively, which is 13% higher than the estimates of \$4.40/GJ (\$0.59/gal) given in Table 11.

These calculations, although based on rather limited data, suggest that fuel from pine, kenaf, or corn biomass is going to cost a minimum of \$5.00/GJ once input cost increases associated with higher fuel costs have been taken into account.

From equation (3) $\frac{dP}{dc_e} = \frac{1}{\bar{y}} \frac{\partial CFb}{\partial c_e} + \frac{ke}{\bar{y}}$ when $\bar{y}$ and k_e are constant.

Assume $\frac{\Delta P}{\Delta c_e} = \frac{dP}{dc_e}$

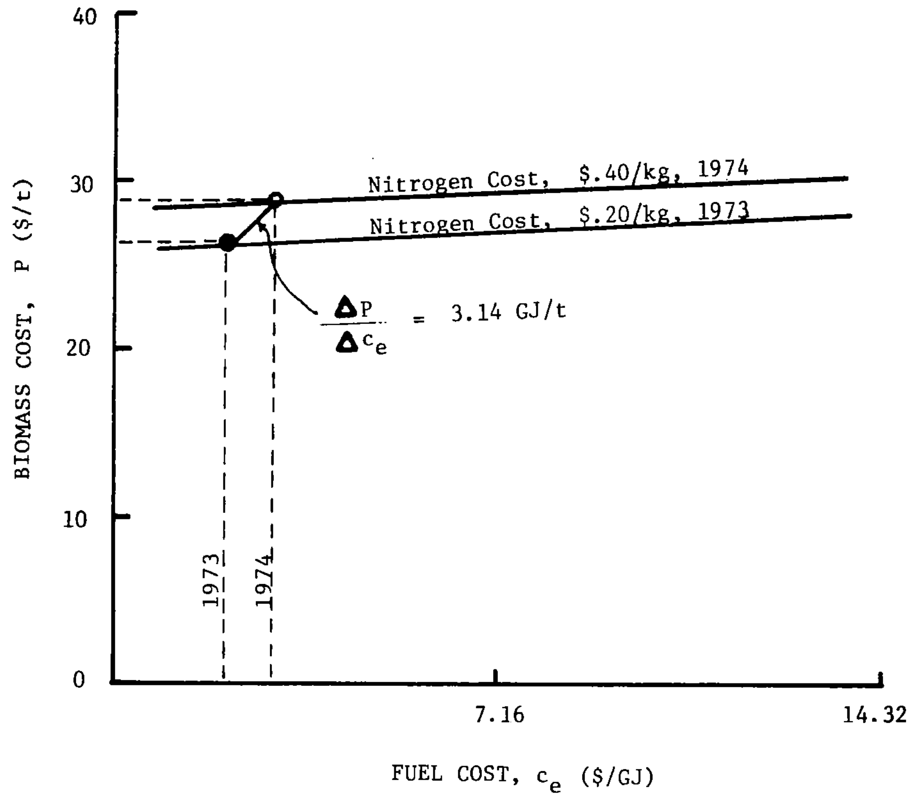


Fig. 11. The effect of fuel and nitrogen costs on the production costs of corn biomass.

Part II. Discussion of Biomass Production Alternatives

Food and Fiber or Fuel? From a world-wide outlook, there is no doubt that a food shortage does continuously threaten and a maldistribution of present food creates tremendous hardship. No case can be made for a world-wide shortage of fuel at the present time, only a distribution that is not to the United States' national advantage. That a future shortage of petroleum is inescapable is certain. That a future shortage of food is nearer and more critical is also certain.

It is, of course, to the United States' national advantage to have, as nearly as possible, a means of providing its own energy supply that can be independent of foreign intervention but would not normally be operated independently because of need for foreign exchange with other friendly countries. In the last two years, the main focus of energy independence has been on fuel energy independence. The growing season of 1974 has caused concern for future food energy sufficiency not only in the developing countries but also in the industrialized countries.

World grain production in 1974 fell some 25 million tonnes below last year's crop. This is an amount equal to the average provision for 100 million people in hungry nations at a time when about 65 million/yr new mouths to feed were added to the world's problem. In the United States, the acreage in food and feed grains was increased by about 20% over 1972 but corn yield dropped 16% below 1973 and the soybean yield dropped 19% below 1973. This was due partly to a fertilizer shortage but mostly to a series of extremely adverse weather conditions over the whole growing season. Only wheat production increased in the United States, by some 8%, but this is only a small percent of what is needed to feed some 400 million undernourished and starving people in the world.

It is against this background that one must examine the humanitarian, economic and national prestige pressures that will ultimately determine whether grown organic matter will be used for fuel synthesis.

The ways that might be considered for the operation of the production-end of a biomass-to-fuel system might be characterized as follows:

Control of Resources	Type of Market
Private	Free
Corporate	Contract
Government	Regulated

Several combinations of these paths may be possible but three examples will be considered here. At the present time, the combination most appropriate to agriculture would be the combination of the control of resources in the hands of the private producer and the price being set by the free market such as the present commodity market. The second possibility worth considering would be the pattern similar to so-called "vertical integration" in the broiler industry and in some vegetable production and processing systems. In this case the resources for production are controlled by the processor and the producer is paid a service fee for his labor and management under a contract price per unit of production. A third possibility is the complete government control of the resources of production and the complete regulation of the return to the producer.

1. In the case of free enterprise in control of the biomass production resources and a relatively free market determining the price on agricultural commodities, it would naturally be the open market price that would influence the producers' planting and harvesting choices. The simple answer to what will bring the producer the highest net return per acre over the long term will determine what he grows - almost. The qualifier is that a new plant species or a new method of growing and harvesting a familiar species would have to promise a substantial increase in net return per acre before the producer would consider it to be worthwhile to learn new practices and tool-up for new enterprises. In 1974, corn grain used for food was worth $131/t, while corn biomass used as corn silage for dairy cattle was valued at $102.50/ton (Table 12). When converted to alcohol, the corn grain and corn biomass dropped in value to $42.50/t and $31.90/t respectively. Regardless of the dollar value of alcohol in the autumn of 1974, the corn biomass would require a market price of substantially more than $52.00/t to compete with corn grain on the open market (Table 13). Likewise, referring to Table 8, if the open market price for biomass from pine, sycamore, alfalfa, or kenaf were $50/t in the autumn of 1974, this would not be likely to pull land out of corn production for 1975 because the margin of profit for the producer, between the production costs in Table 8 and $52/t (times the expected yield), is less than the 1974 margin of profit on the sale of corn grain alone.

At this point, it may be instructive to shift emphasis to the question of "what about producing biomass on 'marginal' land that is not now used for grain production?" A careful examination of this proposition leads to the conclusion that the elements of the cost per tonne for biomass produced on marginal land are all apt to increase with the possible exception of the charge for the land. And it is highly unlikely that biomass production would be more profitable than the production of food, feed or fiber, even on marginal land. This concept of the use of marginal lands for the production of biomass faces another problem in comparison with production of grain or fiber. This is <u>quality land availability</u>, which will be considered later in this report. At this point, however, it can be briefly stated that the vast majority of marginal land <u>is marginal</u> because it (1) lies in a climate where rainfall is insufficient for continuous cropping and/or (2) it has problems of slope, fertility, organic matter, or drainage deficiency that render it unsuitable for sustained removal of all biomass or even crop residue.

TABLE 12. Comparative Value of Corn for Food, Feed and Alcohol, 1974[a].

	Value, $/t
Corn grain, open market	131.00
Corn silage, feed for dairy cattle	102.50
Corn grain: convert to alcohol ($.21/gal. + cost of crop)	42.50
Corn silage: convert to alcohol	31.90

[a] Based on Miller (1973) and Agricultural Prices, Ohio Crop Reporting Service, (June 4, July 2, August 2, September 4 and October 2, 1974). Corn grain averaged $2.83/bu during the 4 months.

TABLE 13. The Minimum Open-Market Price of Whole Plant Biomass[a].

	Expected Biomass Cost[b]	Open-Market Price for Biomass[a]
1970 -		23.43/t ($1.26/bu)
1973 -	$26.03/t	38.85/t ($2.10/bu)
1974 -	28.85/t	52.36/t ($2.83/bu)

[a] Based upon market price of shelled corn. Assumes 18.5 bu shelled corn/t biomass. That is, for each tonne of biomass, 18.5 bushels of shelled corn would be included as a part of the total biomass.

[b] Based upon $98.80/hm^2 land charge and a $98.80/hm^2 return to management.

2. In the case of a scheme of vertical integration where the fuel producing industry has control of the land and resources of biomass production, it is difficult to see where the argument is greatly different from that for individual control of the resources of production. Economics of scale may allow the integrated producer to manufacture or buy fertilizer and chemicals more cheaply, get greater unit efficiency from the farm machinery and arrange low cost transportation. But if the corporate producer can reduce the costs of producing biomass to be used for fuel, he can, by the same techniques, reduce the costs of producing biomass for food, feed and fiber. It is to be expected that he would then market his crop in a manner which would yield the greatest net return. Today and in the foreseeable future, crops sold for food, feed and fiber are likely to bring greater profits than those sold for fuel.

3. The case of complete government control of production resources and regulation of the return to the producer is not likely to be of interest over the long term. In short-term crises, governments can drastically alter individual choices. However, in the long term it is unlikely that any government can operate in a position which would violate the basic laws of thermodynamics or economics or basic human needs for food, clothing and shelter. In any event, governments will be faced with the same set of constraints as corporations or individuals.

Land Availability and Quality. In 1969 there were 1.92 Mm^2 (475 million acres) in crop lands, 1.82 Mm^2 (449 million acres) in pasture lands and 0.45 Mm^2 (112 million acres) in timber lands on the farms of United States (U.S. Govn. Printing Office, 1972). There were 2.60 Mm^2 (643 million acres) of grazing and forested lands not in farms and another 0.79 Mm^2 (194 million acres) in cities and other areas permanently removed from agricultural production. This latter figure is increasing at the rate of about 0.02 Mm^2 (4 million acres) per year. A national land inventory made in 1958 (USDA Misc. Publ. No. 971, 1965) assigns land to one of eight classes according to land use capabilities. Class I land has fertile, level, deep soil with good tilth and no tillage problems. Class IV land is suitable only for occasional or limited cultivation. Class VIII land is totally unfit for commercial plant production. About 2.60 Mm^2 (641 million acres) of the non-federal rural land in the United States is in Classes V-VIII. Of the non-federal land suitable for cultivation in 1958, areas of each class were: Class I, 0.15 Mm^2 (37.2 million acres); Class II, 1.17 Mm^2 (290 million acres); Class III, 1.26 Mm^2 (311 million acres); and Class IV, 0.68 Mm^2 (169 million acres). Taking the total of Classes I-IV, 1.71 Mm^2 (422 million acres) was in cropland, 0.68 Mm^2 (167 million acres) in grazing and pasture and 0.88 Mm^2 (217 million acres) in forests and other. See Table 14.

In the areas of the United States where rainfall exceeds 50.8 cm (20 in.) during the growing season, the land area suitable for cultivation (Class I-IV) but not in cropland in 1958 was: rangeland, 0.26 Mm^2 (65 million acres) and forest, 0.66 Mm^2 (163 million acres) for a total of 0.92 Mm^2 (228 million acres)

TABLE 14. Classification and Use of Non-Federal Rural Land in the United States, 1958[a].

Class[b]	Cropland Mm^2	Grazing & Pasture Mm^2	Forest Mm^2	Other Mm^2	Total Mm^2
I	0.111	0.016	0.015	0.005	0.146
II	0.781	0.173	0.175	0.046	1.174
III	0.619	0.269	0.314	0.056	1.258
IV	0.198	0.218	0.235	0.032	0.683
Total	1.709	0.676	0.739	0.139	3.261
Suitable for Cultivation[c]	1.709	0.263	0.660	-----	2.632

[a] Adapted from USDA, Misc. Publ. No. 971 (1965).
[b] Class V-VIII land (2.595 Mm^2) is not suitable for cultivation.
[c] Refers to Class I-IV land which is already cultivated plus land in areas receiving an excess of 50.8 cm of rain per growing season which is not cultivated but is suitable for cultivation.

of land that could be converted to productive cropland. This makes a total of 2.63 Mm^2 (650 million acres) of land potentially cropable in 1958. This inventory projected a 70.04 Mm^2 (11 million acres) net reduction in cropable land by 1975 due to removal from agricultural use.

Thus, the best estimate from this basic information is that today there are about 2.63 Mm^2 (645 million acres) of cropable land in areas of the United States where rainfall is sufficient to grow cultivated crops regularly. It is estimated that 1.53 Mm^2 (375 million acres) were in cultivated crops in 1974. This leaves a theoretical expansion potential for cultivated crops of 1.1 Mm^2 (270 million acres) by reducing pasture and timber lands.

It might be argued that this land could be spared for production of biomass for conversion to fuel. This argument would conflict with two essential considerations:

1. The United States and the world will probably continue to place a higher priority, through the marketplace, for the use of this land to produce food, feed or fiber than to produce biomass for fuel. (Table 13).

2. Almost none of this land is in Class I where it can be expected to sustain the production and removal of whole plants from cultivated, agronomic crops for biomass conversion.

In reality, there appears to be less than 0.20 Mm^2 (50 million acres) of land in the United States which would be suitable for continuous annual harvesting of all above-ground plant parts, and this acreage is already the prime food production land of the country.

Fertilizer Availability: As has been shown in Section I, biomass production on a large and sustained scale requires large inputs of fertilizer. The 1974 crop year, with its disappointing production figures, suffered from bad weather and a shortage of fertilizer. The overall fertilizer supply appeared to be an estimated 10-20% lower in 1974 than in 1973. This shortage along with the estimated 20% increase in land used for grain crops means that the available fertilizer supply for a given area was down 35-40% from 1973.

A recent World Bank analysis suggests that the shortage of fertilizer, combined with the growing demand for food, means that food grains will remain in short supply. The world is not nearly keeping up with the need for fertilizer manufacturing facilities. It has been estimated that investment in new fertilizer plants should now be at the $8 billion per year level, increasing to $12 billion by 1980. Actual world fertilizer industry expansion is between $4 and $5 billion annually (Kane, 1974).

If biomass were removed from the land for processing into fuel, the processing residue could be returned to the producer and perhaps 90% of the phosphorus and potassium could be returned to the land. However, very little nitrogen would be recovered. In contrast, a culture which leaves grain crop residue on the land results in approximately a 25% nitrogen return, a 40% phosphorus return, and a 75% potassium return. The remainder of the phosphorus and potassium is lost in the sale of the grains.

In view of the above considerations, it would appear that any attempt to use biomass for fuel production will impinge upon the following realities of the world fertilizer shortage:

1. The fertilizer available will tend to be used for food, feed and fiber production.

2. Producers will be reluctant to further decrease their crop yield potential by the removal of the nutrients from their land by the sale of vegetative biomass crops.

World Depression & Isolation:

An alternative picture can be drawn out of world chaos. If, through world depression or other political catastrophe, the U.S. should be forced to exist isolated and without world trade, then there exists the possibility of the development of an industry to convert biomass to fuel. This derives from the simple fact that the U.S. can produce more food, feed and fiber than it can consume as food and clothing and simultaneously would consume more liquid fuel than it can presently produce.

In this case, the economics would adjust to encourage production of biomass for fuel production. In the 1930 depression in the U.S., it was not uncommon for farm families to burn ear corn to keep warm because there was no market for corn and no money to buy fuel. It is certainly hoped that such conditions will never again prevail. But if they did, grown organic matter can be used to produce heat, directly or indirectly.

Part III: The Production of Fuel from Crop Residues

The feasibility of producing fuel from crop residues is dependent on the chemical composition of the residue, the quantity available, ease of collection and distribution density of the residue. Of the crops considered in this report, corn and pine are the most promising sources of residue when the primary uses of these crops are for food, lumber and paper production.

A method of collecting corn residue (stovers) has been developed which permits rapid collection with minimal energy input. This method, which employs a flail mower, blows the material into a wagon where it is hydraulically compressed. Since the corn stover is harvested from the field after the grain is removed, moisture content of the stalks varies from 15-40% (w.b.). Field data for collection of corn stovers (Perry, 1973) indicates residue yields of 5.6 t/hm^2 (Table 15). The total potential yield of corn stover residue is estimated to be 144 million tonnes (Table 16) which represents about 0.4% of the total energy requirement of the United States assuming that corn stovers can be converted to fuel with an efficiency of 50%.

In the past, corn stover residue, because of its low digestibility and nutrient levels, has been used as a roughage feed for maintenance rations of cattle (Schneider, 1947). However, the use of corn residue for fattening rations appears feasible if the stalks are finely ground and urea pellets are added at the rate of 2% during ensiling (Conrad, 1974). Although research results are not available, it is Conrad's contention that a ration of finely ground stover could give rates of gain over 1/2 kg per day in beef animals between 250 and 500 kg of body weight. This would allow 1 kg of corn stover plus .02 kg of urea to replace .4 kg of shelled corn with a conversion ratio of 1 kg of stover for each .1 kg of beef produced. Dollar value of the stover when ready to feed would be near $40/t based on replacing corn grain valued at $131/t and a charge of $10/t for recutting, hauling and packing corn stover in a silo. It is estimated that if only one-half of all corn residue were used for beef production, 7.2 million tonnes of beef could be produced, (enough to feed 144 million Americans per year assuming the per capita consumption of beef is 50 kg), and 28.8 million tonnes of corn grain would be freed for the export market. Thus, although corn stover can be converted to fuel, its use as an animal feed has even greater potential.

Another problem associated with collecting corn stovers for conversion to fuel is distribution density of the residue. A bio-conversion plant with the capacity to convert 1000 t/day of dry biomass would require corn stover from approximately 64,000 hm^2 of land. This is equivalent to an area 36 km on a side if 50% of the land is cropped to corn grain. If hauling cost per tonne were $0.04/kg (Graham, 1974), the cost would increase at least $0.81 per tonne (assuming corn stover is 33% water). An examination of land cropped as a percent of total land area indicated that only in Iowa would 50% of the land be cropped to corn grain if all the cropland were put into corn production. The effect of percentage land in corn grain on hauling distance is given in Figure 12.

A third problem is that removal of crop residue from the land for conversion to fuel is not desirable on sloping lands or on lands with less than 3% organic matter in the soil surface. This is because of erosion dangers and the need to maintain reasonable levels of soil organic matter which enhance soil structure and water-holding capacity. If erosion occurs or surface soil organic matter level drops below 3%, the capability of the soil to support crop growth is restricted (Buckman and Brady, 1960). Thus, on the basis of land management it is estimated that only 14.6 million hm^2 of land (Class I land)

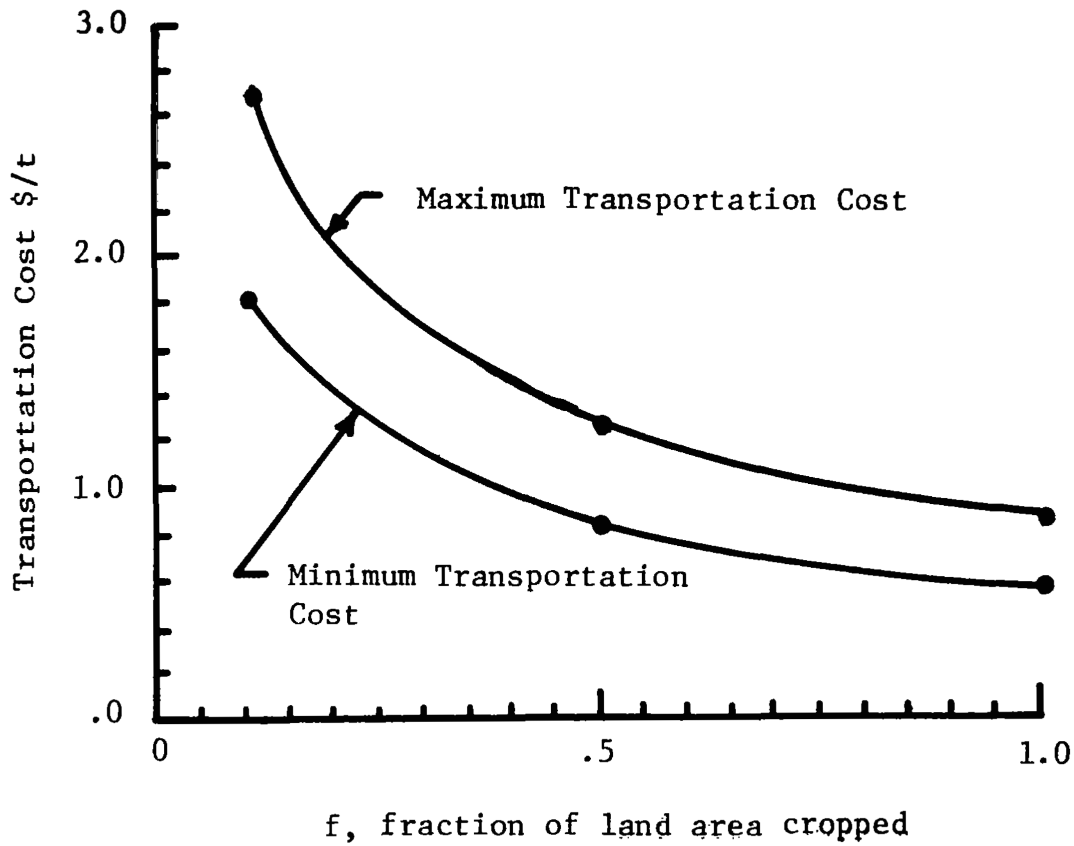


Fig. 12. Cost of transporting biomass residue to a bio-conversion plant with a yearly capacity of 360,000 t. Dry biomass residue is 5.6 t/hm^2. Hauling cost is \$0.04/t·km.

in the United States would be suitable for crop residue removal on a semi-continuous basis (USDA Misc. Publication 971, 1965).

Forest residues associated with logging operations are a potential source of biomass residue. However, "today's equipment and methods to collect, load, and transport logging residues are generally uneconimic ... unless end product values or new marketing arrangements can be found", (Grantham et al., 1974). Field data for the collection of pine residues indicate potential yields of 13.8 t/hm^2 per cycle for pine (Table 15). The total annual potential residue from logging wastes is estimated to be 39 million tonnes (Table 16) which represents about 0.1% of the total energy requirement of the United States when residues are converted to fuel with 50% efficiency.

In the past, most forest residues have been burned in place, windrowed, or crushed without being used for fuel, lumber, or fiber (Belluschi, 1974) due to the high collection cost and low market value of the product. Based on Belluschi (1974) the cost of collecting biomass is an estimated \$8.76/t of dry material while cost data adapted from Grantham et al. (1974) in the Pacific Northwest suggests a cost of \$17.68/t. In addition, Grantham estimates that transportation costs would be about \$15/t if the logging residues were transported to a utilization site at a distance of approximately 100 km.

That forest residues will be collected and removed from the logging site in the future appears likely. Pierovich and Smith (1973) note that forest residues left in the field are fire hazards, affect quality of water from water sheds and interfere with timber management. Also, future on-site buring is likely to decrease because of air pollution and government regulations. However, even though logging residue may be collected in the future, its use for fuel production is unlikely. The major use of the collected residue will be for fiber production (Koch, 1973, 1974, Koch and Mullen, 1971, Herrick and Brown, 1967, Young, 1968, Grantham et al., 1974 and Belluschi, 1974) as the United States' demand for lumber and fiber is expected to increase between 87 and 144 million tonnes over the next 25 years (Table 17).

In addition to logging residues, there is considerable waste generated at wood processing plants. In 1970 it was estimated that over 76.1 million tonnes of residue were generated annually with about 50% of these being used in the manufacture of pulp, particle board, and other products (Table 18). Of the unused residue, 27 million tonnes were produced at primary processing plants where collection for fuel is feasible.

Grantham, et al. (1974) suggest the short-term use of logging and mill residues for fuel production on the Pacific Coast where residue concentrations are relatively high. This would partially alleviate power needs of local plants while alternate sources of power are being developed. However, on a long-term basis, the increasing demand for pulp and fiber sources will likely mean that most all of the lumber and mill residue will be used for non-fuel

TABLE 15. Annual Yield and Cost of Crop Residues.

Crop	Harvestable Yield (t/hm^2)	Nutrients Removed ($/t)	Harvesting ($/t)	Total ($/t)
Corn stover[a]	5.6	4.41	4.38	8.80
Timber residue[b]	13.8	2.46	6.30	8.76

[a] Nutrients removed in biomass (normally available to following crop): 28 kg N, 10 kg P_2O_5 and 72 kg K_2O/hm^2. Harvesting cost from Henderson, 1973.

[b] Limbs, tops, and stems 0.10 m diameter. Nutrients removed in biomass (normally available to following crop): 56 kg N, 13 kg P_2O_5 and 39 kg K_2O/hm^2. Yield and harvest cost adapted from Belluschi, (1974). Harvest cost assumed to be 50% of pulpwood cost, which is $15/cord.

TABLE 16. Potential Cropable Area and Crop Residue Annual Yields in the United States - Corn and Timber.

Crop Residue	Area 10^6 hm^2	Yield 10^6 t	Energy Equivalent 10^6 GJ
Corn stovers[a]	25.8	144	2229
Timber residue[b]	----	39	602
Total		1183	2413

[a] Based on corn acreage harvested for grain in 1971, (U.S. Govn. Printing Office, 1972).

[b] Timber residue estimate based on following assumptions: 396 million m^3 (14,000 million ft^3) of timber cut in commercial forests in 1970 (U.S. Govn. Printing Office, 1972); percentage of timber residue is 15%, which is the value given by Belluschi (1974) for pine trees; density of timber equals 40 lb. dry weight per ft^3.

TABLE 17. U.S. Timber Annual Production and Consumption, 1970 and 2000[a].

	Roundwood (10^6 t)[b]		Saw Timber (10^6 t)	
	Production	Consumption	Production	Consumption
1970	133	144	54	57
2000, assuming 1970 relative prices[c]	248	254	89	91
2000, assuming rising relative prices	186	218	62	70

[a] Table adapted from USDA Forest Service, FRR-20 (1973), Tables 152 and 153.
[b] Dry weight.
[c] Relative prices rising from 1970 trend level, 1.5% per year for lumber, 1.0% per year for plywood, miscellaneous products and fuelwood, and 0.5% per year for paper and board.

TABLE 18. U.S. Timber Annual Residue, 1970 and 2000[a].

Residue[b]	1970 Total Residue[b] 10^6 t	1970 Unused Residue 10^6 t	Projected Residue - 2000[c] 10^6 t
Logging residue (roundwood) from growing stock	18.14		19.28
Logging residue from saw timber	3.49		2.64
Logging residue from non-growing stock above 4" diameter[d]	18.14		
Primary wood processing plant residue	43.21	11.23	
Secondary wood processing plant residue[e]	10.21	9.07	
Bark residue[f]	22.68	15.65	

[a] Information from USDA Forest Service, FRR-20, (1973).
[b] Dry weight.
[c] Based on 1970 level management.
[d] Estimate based on a Pacific Coast study of old-growth stands.
[e] Estimate based on a Midwest study of secondary manufacturing plants.
[f] Bark accumulated at primary processing plants. Estimate based on limited studies and informed judgement.

purposes. Thus the potential availability of timber residue for fuel production in the future appears to be small.

CONCLUSIONS

That grown organic matter can be used for the production of liquid, gaseous or solid fuels is technologically beyond question. That it will be or should be so used involves several considerations which may not presently support a national decision to move to develop such a technology. Some of these considerations are as follows:

1. Biomass production for conversion to fuel would compete directly with food, feed and fiber production for management talent, production capital, energy and material inputs, and fertile land.

2. In this competition, the grown product at the present is considerably more valuable for food, feed or fiber than for conversion to fuel, based upon any realistically predicted synthetic fuel price. The producer is apt to sell to the higher bidder.

3. The commonly held belief that much can be done on our "marginal lands" to produce fuel is unrealistic. Most unused land is marginal because it is (a) inaccessible, (b) low in fertility, (c) undrained, (d) susceptible to severe erosion when tilled, (e) too dry, or combinations of these. Any such land can be brought into efficient production of fuel biomass only by the application of the same management, capital and input resources as would be required to produce food on it. Under present circumstances, it would be more profitable to reclaim it for food production.

4. The cost of fuel is so much an input into the cost of producing grown organic matter (directly in fuel and indirectly in machinery, fertilizer, chemicals and irrigation water) that the combination of cheap grown organic matter and expensive fuel is not likely to occur at any time other than at very transient, or catastrophic conditions.

5. There are no plant species that will produce biomass more abundantly or more efficiently in the U.S. than our common agricultural crops now grown and/or our forest species.

6. With regard to the use of crop or forest residues for conversion to fuel, the difficulties to be overcome are (a) most food or feed crops' residues are more valuable as animal feed than for fuel, (b) most crop and forest residues are too widely dispersed to be efficiently collected to a conversion plant, (c) forest residues that are concentrated are more valuable for fiber use than for fuel conversion and (d) only a small portion of the U.S. land capable of crop production can be continuously stripped of

all above-ground organic residue without severe loss of fertility and/or severe erosion. Organic residue fed to animals can be returned to the soil in manure which returns needed organic matter and some essential nutrients.

The general conclusion of this study is:

Given (1) the existing and foreseeable tradeoffs between food and fuel as a goal of grown organic matter production, (2) the other energy conversion technologies that show promise, and (3) the existence of a reasonable level of world trade, the U.S. land use priority will continue to be on food production to the exclusion of a viable industry for conversion of grown organic matter to fuel.

CONCLUDING REMARKS

Modern agriculture is the result of thousands of years of man's attempt to improve the overall effectiveness of culturing the photosynthetic process. The need for such extensive culturing of the photosynthetic process derives from the fact that humans and all other animals require a diet of diverse materials from the plant tissues for their nutritional well-being. All of these nutrients have one thing in common - they are large, rather complicated molecules built from the atoms of carbon, hydrogen, oxygen, nitrogen, etc.

Photosynthesis, even in the best plants man has bred, is a very inefficient process of collecting solar energy when measured in heat energy efficiency. This inefficiency derives from the fact that these complicated molecules, which are essential nutrients to animals, require tremendous inputs of heat and chemical energy to be organized and synthesized from simple atoms within the growing plant. This very poor thermodynamic efficiency of green plants is tolerated in this earth's society only because <u>there is no other practical way to synthesize these essential nutrients</u>. The fact that solar energy is collected very poorly by photosynthesis is of <u>no consequence</u> when viewed against the only available alternative.

On the other hand, the very simplest of substances containing carbon and/or hydrogen atoms represent the most desirable, clean-burningfuels. There is no inherent necessity for complicated molecules to be built, at great cost of heat and chemical energy inputs, where heat from the burning of fuel is the desired product.

Thus, here is a place where the "conventional wisdom" of society as reflected in the market place (as presented in Part I of this report) is strongly supported by the logical analysis of the thermodynamics of the system. Whereas the inefficiencies of photosynthetic production of starches, amino acids, fats, etc. must be tolerated as the only way to meet human nutrient requirements, where is the thermodynamic justification for adding the inefficiencies of converting grown organic matter back to simple hydrocarbons to be put through a combustion process to obtain heat? If heat is the desired energy form for the application, the direct collection of solar heat must surely be more efficient than the photosynthetic route for the majority of heat energy requirements in the residential and commercial sectors. Thus, some of the present use of liquid and gaseous fuels in these sectors could be avoided, and the use of organic wastes to produce methane might be regarded as a supplementing technique in areas where critical shortages still would exist.

In the case where mechanical energy is the desired energy form for the application, and electrical energy is not adaptable, a clean-burning liquid fuel is necessary. Some of this need could be met by the conversion of ligneous materials, either wastes or whole plants grown on Class IV to VIII land.

Infusion of Energy R & D funds to investigate ways to produce liquid fuels from ligneous organic matter for essential mechanical propulsion would appear to be of merit. Vast programs to investigate the growing of organic matter on tillable, arable land for the conversion to heating fuels should be subjected to the greatest scrutiny.

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APPENDIX A

BIBLIOGRAPHY OF BIOMASS PRODUCTION, INPUTS, CULTURE, AND CLIMATIC EFFECTS

by Rochelle D. Kline, H. J. Mederski, H. M. Keener, and Warren L. Roller

BIOMASS PRODUCTION OF SPECIFIC CROPS

Agrawal, J.P. and N.K. Jain. Seedbed preparation, intertillage operations and chemical control for sugarcane growth and quality. Agron. J. 63(2):319-321. 1971.

The maximum fresh cane yield at approximately one year of age was 36.8 t/hm^2 (8.5 t dry matter/$hm^2 \cdot yr$ assuming 76.8% moisture) in Kanpur, Northern India.

Atkins, A.M., O.G. Merkle and Paul E. Pawllisch. Visual estimates and clipping plot size for evaluating the forage potential of small grain varieties. Agron. J. 61(1):88-91. 1969.

Forage yields of small grains in Texas locations ranged from 0.8 to 1.6 t dry matter/$hm^2 \cdot yr$ in 1960.

Barrett, Otis Warren. <u>The Tropical Crops</u>. New York. MacMillan Co. 1928.

From 2 to 10 crops of ratoon suckers may grow from old sugarcane roots. Fresh weight yields of stalks range from 44.8 to 268.9 t/hm^2 (10.4 - 62.4 t dry matter/hm^2 assuming 76.8% moisture). Fields do not need replowing after every crop.

Breaux, R.D., R.J. Matherne, R.W. Millhollon and R.D. Jackson. <u>Culture of Sugarcane for Sugar Production in the Mississippi Delta</u>. USDA-ARS. Agric. Handbook No. 417. 1972.

Production of Mississippi sugarcane in 1972 was approximately 56 t fresh cane/$hm^2 \cdot yr$ (13 t dry matter/$hm^2 \cdot yr$ assuming 76.8% moisture). A complete summary of production factors is included.

Burton, Glen W. Epistasis in pearl millet forage yields. Crop Sci. 8:365-368. 1968.

The maximum dry forage yield of singlecrosses of pearl millet was 10.5 $t/hm^2 \cdot yr$. The experiments were carried out in Tifton, Georgia.

Chin, Nyeok Yoon. Growth studies on sugarcane. The Malaysian Agric. J. 48(2): 47-59. 1971

The maximum dry matter yield of sugarcane harvested after one year in Malaysia was 27.9 $t/hm^2 \cdot yr$.

Corley, R.H.V., B.S. Gray and Ng Siew Kee. Productivity of the oil palm (*Elaeis guineesis* Jacq.) in Malaysia. Expl. Agric. 7:129-136. 1971.

In Malaysia, the mean crop growth rate of mature oil palms was 29.8 t of dry matter/$hm^2 \cdot yr$, 16.9% of which was oily matter. The maximum crop growth rate was 33.4 t of dry matter/$hm^2 \cdot yr$ at the age of 10.5 years. Total energy fixed was 629.0 GJ/$hm^2 \cdot yr$. Photosynthetic efficiency was 2.2%. Additional information on leaf area index, net assimilation rate, and harvest index is included.

Curtin, R.A. Increasing the production of eucalypt forests in New South Wales. Austral. Forestry 34(2):97-106. 1970.

Growth rates up to 14.8 t dry matter/$hm^2 \cdot yr$ (based on 200 ft^3/acre·year and assuming 66 lb/ft^3) have been observed in small plots of eucalyptus. Typical yields in New South Wales, Australia range from 0.2 t dry matter/$hm^2 \cdot yr$ (based on 3 ft^3/acre·yr and assuming 66 lb/ft^3) to 3 t dry matter/$hm^2 \cdot yr$ (based on 40 ft^3/acre·yr and assuming 66 lb/ft^3) due to poor quality growing stock.

FAO Africa Survey: Report on the Possibilities of African Rural Development in Relation to Economic and Social Growth. Conference. C 61/15. Food and Agriculture Organization of the United Nations. 1961.

Bananas, var. Poyo, in the Ivory Coast, produce from 30 to 50 t fresh weight/$hm^2 \cdot yr$ (7.5 - 12.5 t dry matter/$hm^2 \cdot yr$ assuming 75% moisture) with the use of improved methods. Yields of several other crops are given.

Follett, R.F., W.R. Schmehl and F.G. Viets, Jr. Seasonal leaf area, dry weight and sucrose accumulation by sugarbeets. J. of Amer. Soc. of Sugar Beet Technologists 16(3):235-252. 1970.

The yield of sugarbeet roots and tops in Fort Collins, Colorado (40°35'N) was 21.1 t of dry matter/$hm^2 \cdot yr$. Fertilizer nitrogen was applied. Solar radiation and temperature measurements are reported.

Forrest, W.G. and J.D. Ovington. Organic matter changes in an age series of Pinus radiata plantations. J. Appl. Ecology 7:177-186. 1970.

In Tumut, New South Wales, Australia, the maximum above-ground production of oven-dry organic matter in 5-7 year old radiata pine plantations was 25.9 $t/hm^2 \cdot yr$. Trees alone accounted for 23.3 $t/hm^2 \cdot yr$. In twelve years, total above-ground accumulation of dry organic matter was over 130.0 t/hm^2, 87% of which was trees.

Forrest, Warrick G. Biological and economic production in radiata pine plantations. J. Appl. Ecology 10(1):259-267. 1973.

In southern New South Wales, the maximum above-ground biological production of radiata pine was 26 t of oven-dry matter/$hm^2 \cdot yr$ between the ages of 6 and 7 years. During a crop rotation, biological production averaged 16 to 18 $t/hm^2 \cdot yr$.

Gupta, B.S., D.E. Johnson, F.C. Hinds and H.C. Minor. Forage potential of soybean straw. Agron. J. 65(4):538-541. 1973.

In Illinois the maximum yield of hand-harvested, oven-dried soybean straw was 4.4 t/hm^2 for the mature, field-grown cultivar 'Dare'.

Halacy, D.S., Jr. The Coming Age of Solar Energy. New York, Evanston and London. Harper and Row, Publishers. 1963.

The firm of Arthur D. Little demonstrated the commercial production of algae. Actual yield was 44.8 t dry matter/$hm^2 \cdot yr$, but an estimated 78.4 t dry matter/$hm^2 \cdot yr$ may be possible with the improvement of the algae plant.

Hanway, J.J. and C.R. Weber. Dry matter accumulation in soybeans (Glycine max [L] Merrill) plants as influenced by N, P and K fertilization. Agron. J. 63(2):263-266. 1971.

The final dry plant weight of soybeans in experiments in Ames, Iowa was 12.4 $t/hm^2 \cdot yr$ averaging several fertilizer treatments. This figure does not include leaf fall or roots.

Herrick, Allyn M. and Claud L. Brown. A new concept in cellulose production - silage sycamore. Agric. Sci. Rev. USDA. 5(4):8-13. 1967.

Coppice yields of young hardwoods in propagation experiments were greater than 56.0 t of green matter/$hm^2 \cdot yr$ (22.4 t dry matter/$hm^2 \cdot yr$ assuming 60% moisture). The authors believe that sycamore and sweetgum trees could presently yield more than 22.4 t of dry matter/$hm^2 \cdot yr$ with dense planting and 2-3 year coppicing. With improved silvicultural methods and genetic gains, yields in excess of 44.8 t of dry matter/$hm^2 \cdot yr$ may be possible. Harvesting equipment is discussed.

Hybrid Corn Performance Tests in Wyoming, 1971-72. Agric. Expt. Sta. University of Wyoming, Laramie. Res. J. 81. February 1974.

The maximum yield of corn forage was 18.3 t dry matter/$hm^2 \cdot yr$ at Torrington with var. corn King 1122. The maximum grain yield was 8.8 t dry matter/$hm^2 \cdot yr$ at Torrington with var. Payco SX860.

Jellum, M.D., D.G. Cummins and C.T. Young. Yield and chemical characteristics of corn (_Zea mays_ L.) types. Agron. J. 65(6):933-936. 1973.

Several corn varieties were planted at seven Georgia locations in 1971. Pioneer 3009 at Leesburg in the Coastal Plains Region gave a maximum grain yield of 9.6 t dry matter/$hm^2 \cdot yr$. The maximum dry matter yield of silage was 14.8 t/hm^2 with Funk G-4949 at Experiment, Georgia.

Jensen, Neal F. Registration of Yorkstar Wheat. Crop Sci. 8(5):641. 1968.

The mean grain yield of Yorkstar wheat (_Triticum aestivium_ L. em Thell.), a soft, white winter wheat of medium height is 3.1 t dry matter/$hm^2 \cdot yr$ (based on 53.4 bu/acre·yr and assuming 60 lb/bu and 13% moisture). The mean yield of Genesee is 2.9 t dry matter/$hm^2 \cdot yr$ (based on 49.07 bu/acre·yr and assuming 60 lb/bu and 13% moisture).

Mays, D.A. Corn silage yield as affected by different harvesting techniques. Agron. J. 60:97-98. 1968.

Yields of dried corn silage ranged from 10.0 to 11.7 t/$hm^2 \cdot yr$ in Muscle Shoals, Alabama.

McDole, R.E. and C.E. Dallimore. Potato cropping rotations in coarse-textured soils in southeastern Idaho. Univ. of Idaho College of Agriculture, Coop. Ext. Serv., Agric. Expt. Sta. Current Info. Serv. Series No. 200. March 1973.

The maximum yield of fresh potatoes in rotation-fumigation trials at Fort Hall, Idaho, was 48.1 t/hm^2·yr (9.7 t dry matter/hm^2·yr assuming 79.8% moisture).

Mozzer, Otto Luiz, Margarida M. De Carvalho and Edywald Soeiro Emrich. Competicao variedades e hibridos de capimelefant (Pennisetum purpureum L.) para formacaode capineiras em sole de cerrado. (A comparison of elephant grass [P.p.] varieties in campo cerrado soils). Pesqui Agropecu. Bras. 5:395-403. 1970. [Abstract].

The maximum dry matter yield of twelve varieties of elephant grass grown in the state of Minas Gerais, Brazil, was 28.9 t/hm^2 over a two-year period with var. Mineiro. Fertilizers were applied.

Newell, L.C. Effects of strain source and management practice on forage yields of two warm-season prairie grasses. Crop Sci. 8:205-210. 1968.

Ten strains each of switchgrass (Panicum virgatum L.) and big bluestem (Andropogon gerardi Vitman and A. halli Hack.) were grown in three Nebraska environments over a four-year period. Maximum yields of the two tall prairie grasses were 30.2 and 26.1 t dry matter/hm^2·3 years for switchgrass variety 'Blackwell' and bluestem 4 x 7 hybrid, respectively. Yields increased considerably during the last two years with the addition of nitrogen fertilizer.

Ochse, J.J., M.J. Soule, Jr., M.J. Dijkman and C. Wehlburg. Tropical and Subtropical Agriculture Vol. II. New York. MacMillan Co. pp. 1139-1146. 1961.

Ramie (Boehmeria nivea Gaud.), a perennial fiber plant grown in Florida, may yield up to 67.5 t of green fiber/hm^2·yr (26.6 t dry matter/hm^2·yr assuming 65% moisture) with three cuttings. Fertilizer requirements are high. Other information on climatic and soil requirements, culture, harvesting, processing and uses of ramie is included.

Panje, R.R., P.S. Gill and Bakhtawar Singh. Effect of number and position of buds on a set on clump formation and yield of sugarcane. Ind. J. of Agric. Sci. 41(5):431-440. 1971.

Fresh harvest weights of sugarcane grown at the Indian Institute of Sugarcane Research at Lucknow in 1962-63 were 44.2 and 49.3 t/hm^2·yr (10.3 and 11.4 t dry matter/hm^2·yr assuming 76.8% moisture) for 3 and 5-budded sets, respectively.

Pollard, D.F.W. Above-ground dry matter production in three stands of trembling aspen. Can. J. For. Res. 2(1):27-33. 1972. [Abstract].

Trembling aspen (*Populus tremuloides* Michx.) stands, aged 6, 15 and 52 years exhibited net annual above-ground (stems and branches) production of 6.9, 7.0 and 1.3 t of dry matter/$hm^2 \cdot yr$, respectively in Ontario. The following year, annual foliage production was 2.6, 2.6 and 1.5 t of dry matter/$hm^2 \cdot yr$ for the 7, 16 and 52 year old stands, respectively.

Propsects of the World Food Supply. A Symposium. National Academy of Science. Washington, D.C. 1966.

The highest average yields for various crops in the United States, India, Egypt and Japan were potatoes (U.S.) - 20.9 t/$hm^2 \cdot yr$ (4.2 t dry matter/$hm^2 \cdot yr$ assuming 79.8% moisture); cassava (India) - 7.2 t/$hm^2 \cdot yr$ (2.6 t dry matter/$hm^2 \cdot yr$ assuming 63.8% moisture); bananas (Egypt) - 18 t/$hm^2 \cdot yr$ (4.5 t dry matter/$hm^2 \cdot yr$ assuming 75% moisture); tomatoes (U.S.) - 28.1 t/$hm^2 \cdot yr$ (1.8 t dry matter/$hm^2 \cdot yr$ assuming 93.5% moisture); and onions (U.S.) - 30.8 t/$hm^2 \cdot yr$ (3.4 t dry matter/$hm^2 \cdot yr$ assuming 89% moisture). The energy contents of these crops in MJ/t are potatoes (3763.7), cassava (14636.7), bananas (3763.7), tomatoes (920.0) and onions (1589.1). Tables of information on these and other crops are presented.

Rice in the United States: Varieties and Production. USDA-ARS. Agric. Handbook No. 289. 1966.

The average rice yield in the United States was 4.0 t/$hm^2 \cdot yr$ (0.4 t dry matter/$hm^2 \cdot yr$ assuming 91% moisture) in 1963. The handbook gives an extensive account of rice production in the United States.

Ross, W.M. *Culture and Use of Grain Sorghum*. USDA-ARS. Agric. Handbook No. 385. 1970.

The highest yield of grain sorghum during the years 1958-68 was 3.5 t/$hm^2 \cdot yr$ (3.1 t dry matter/$hm^2 \cdot yr$ assuming 11% moisture) in 1966. Over 80% of the grain sorghum production is in Texas, Kansas and Nebraska. Information on the culture and use of the crop is included.

Sim, E.S. Dry matter production and major nutrient contents of black pepper (*Piper nigrum* L.) in Sarawak. The Malaysian Agric. J. 48(2):73-93. 1971.

The annual yield (average of ages 3 1/2 to 17) of dry matter from the black pepper plant (*Piper nigrum* L.) grown in Sarawak, East Malaysia is 11.4 t/hm^2·yr. The estimate of nutrient losses is as follows: 106 kg N, 18 kg P_2O_5, 94 K_2O, 14 kg MgO and 48 kg CaO/hm^2·yr.

Singh, R.D., Premchand and A. Rahaman. Herbage growth of pearlmillet-napier-grass hybrid when compared with other grasses. Ind. J. Agric. Sci. 42(3):218-222. 1972.

Yields were lower for pearlmillet-napier hybrid and local napier than for other grasses. Mean annual dry matter yields for 1966-68 were *Andropogon gayanus* (14.3 t/hm^2·yr), *Brachiaria brizantha* (14.3 t/hm^2·yr), pearlmillet-napier hybrid (6.3 t/hm^2·yr) and local napier (4.9 t/hm^2·yr). The higher yields were attributed to higher LAI values.

Stiell, W.M. and A.B. Berry. Yield of unthinned red pine plantations at the Petawawa Forest Experiment Station. Dept. of the Environment. Canadian Forestry Service. Publ. No. 1320. 1973.

The yield of red pine (*Pinus resinosa*) at the age of 20 years from planting was 136.2 t dry matter/hm^2·20 yr or 6.8 t/hm^2·yr (based on 3842 ft^3/acre·20 yr and assuming 31.65 lb/ft^3).

Taliferro, C.M., C.E. Denman, R.D. Morrison and D. Holbert. Cultivar-environment interaction study of alfalfa yields in Oklahoma. Crop Sci. 13:619-622. 1973.

Of fourteen alfalfa cultivars tested at five locations in Oklahoma, Kansas Common had the highest mean dry matter yield of 10.6 t/hm^2·yr averaged over the five locations.

Wadsworth, Frank H. *The Regeneration of Tropical Forests by Planting*. Proc. of the Fifth World Forestry Congress 3:1947-1952. 1960.

In tropical Australia and Indonesia, the average yearly growth increments of gymnosperms between the ages of 25 and 37 years range from 3.4-6.7 t dry matter/hm^2·yr (based on 200-400 ft^3/acre·yr and assuming 37 lb/ft^3). Included are species of pine, agathis and araucaria. *Eucalyptus deglupta* in tropical Australia has a growth increment of 29.9 t/hm^2·yr (based on 486 ft^3/acre·yr and assuming 55 lb/ft^3).

Whitakre, Thomas W., Arden F. Sherf, W.H. Lange, Clark W. Nicklow and John D. Radewald. Carrot Production in the United States. USDA-ARS. Agric. Handbook No. 375. 1970.

The average carrot yield in the important carrot producing states was 24.2 t fresh weight/$hm^2 \cdot yr$ (2.8 t dry matter/$hm^2 \cdot yr$ assuming 88.6% moisture) during 1966. Other information includes field management practices, breeding, genetics and diseases as they affect carrot production.

Williams, C.N., and K.T. Joseph. Climate, Soil and Crop Production in the Humid Tropics. Singapore. Oxford Press. 1970.

The effects of climate, temperature, water stress and other factors on tropical plants are discussed. The average annual sugarcane yield (1943-1963) in Barbados was 96.4 t/hm^2 (22.4 t dry matter/hm^2.yr assuming 76.8% moisture).

Winter, S.R. and A.J. Ohlrogge. Leaf angle, leaf area and corn (Zea mays, L.) yield. Agron. J. 65(3):395-397. 1973.

Leaf angles of corn at Purdue University Agronomy Farm were mechanically adjusted from 45° to 10° or 15°. Management practices and fertilization were optimum for maximum corn production. The maximum grain yield (0% moisture) was 11.2 t/hm^2 for Pioneer 3369A, a tall, full-season hybrid with a mean seasonal LAI of 5.8.

CLIMATIC EFFECTS DATA

Alexander, Alex G. and George Samuels. Controlled temperature studies of growth, enzymology and sucrose productivity by two sugarcane varieties in Puerto Rico. J. Agric., Univ. of P.R. 52(3):204-217. 1968.

A more rapid growth rate was exhibited by sugarcane plants exposed for ten days to controlled-climate temperatures of 26.7 - 29.4°C (80-85°F) than by those exposed to 12.8 - 15.6°C (55-60°F) temperatures. P.R. 980, a high tonnage variety exhibited a higher growth rate under warm conditions than did P.R. 1059, a high-sucrose variety.

Dewey, W.G. and R.F. Nielson. Effect of early-summer seeding of winter wheat on yield, soil moisture and soil nitrate. Agron. J. 61(1):51-55. 1969.

Winter wheat was planted at monthly intervals from June through October at three dry and four irrigated sites in northern Utah. Dryland sites averaged 25.4-35.6 cm of rainfall per year. Maximum grain yields were 3.0 and 4.5 t/hm^2 (2.6 and 3.9 t dry matter assuming 13% moisture) for wheat planted in September at Blue Creek, a dryland site, and Logan, an irrigated site, respectively.

Rutger, J.N. Relationship of corn silage yields to maturity. Agron. J. 61(1):68-70. 1969.

Ten-year records (1957-66) of corn silage yields in New York show dry matter yields of approximately 10 to 13 $t/hm^2 \cdot yr$. Early varieties were grown at high elevations in northern New York where the growing season is 150 days. Medium varieties were grown along the Lake Ontario plain where the growing season is 165 days.

Stanford, George and Albert S. Hunter. Nitrogen requirements of winter wheat (*Triticum aestivium*, L.) varieties Blueboy and Redcoat. Agron. J. 65(3):442-447. 1973.

Plots of September-planted red winter wheat were treated with five different nitrogen rates in either November or April. The maximum total oven-dry yield (grain plus straw) was calculated as 12.7 t/hm^2 averaging spring and fall nitrogen applications. This yield was obtained with variety Redcoat planted at the Agronomy Research Farm in Centre County. Rainfall received between November and the July harvest was 130.3 cm.

Watschke, T.L., R.E. Schmidt, E.W. Carson and R.E. Blaser. Temperature influence on the physiology of selected cool season turfgrasses and burmudagrass. Agron. J. 65:591-594. 1973.

In Virginia, one warm-season grass, Tifgreen burmudagrass (Cynodon spp.), and eight cool season grasses were grown under two temperature regimes. K8-154 red fescue and K9-116 ryegrass produced the highest yields of the cool season grasses under the high temperature regime. Information on photosynthetic and photorespiration rates in normal and O_2-reduced atmospheres is given.

Zuber, M.S. Date-of-planting studies with corn. North Missouri Research Center. Bull. 832. 1966.

Eight varieties of corn representing four maturity groups were planted at the North Missouri Research Center in Spickard from 1960-64. Of all maturity groups, the maximum grain yield was 3.4 $t/hm^2 \cdot yr$ (2.9 t dry matter/$hm^2 \cdot yr$ assuming 15% moisture) with the 140-day maturity group in 1963.

CULTURAL PRACTICES - EFFECTS ON CROP PRODUCTION

Adams, W.E., H.D. Morris, Joel Giddens, R.N. Dawson and G.W. Langdale. Tillage and fertilization of corn grown on lespedeza sod. Agron. J. 65(4):653-655. 1973.

In the Piedmont Land Resource Region of Georgia, corn was planted on soil where a ten-year, 32 t/hm^2 yield of syricea lespedeza was cut and left in the field. Various tillage and fertilization schemes were used. The maximum grain yield was 6.4 t dry matter/hm^2·yr with conventional soil preparation and planting, lespedeza residue present and micronutrients added. Over a five-year period, any benefits from lespedeza on the soil largely disappear.

Alberda, Th. Dry matter production and light interception of crop surfaces. IV. Maximum herbage production as compared with predicted values. Neth. J. Agric. Sci. 16:142-153. 1968.

With optimum supplies of water and nutrients, hay-type Barenza 58-3 ryegrass produced 3.1 t/hm^2 of dry matter in five cuttings. Data from the Netherlands experiments were used to make a table which allows one to predict total herbage production for various cutting schemes.

Alessi, J. and J.F. Power. Effects of plant population, row spacing and relative maturity on dryland corn in the northern plains. Agron. J. 66(2): 316-319. 1974.

Mandan, North Dakota, in the northern Great Plains is typified by a short growing season with rising temperatures and declining precipitation as the season progresses. Thus, crop management is of prime importance. The maximum yield of oven-dry matter from three years of corn management experiments was over 12.0 t/hm^2·yr with var. Pioneer 3872, which has a relative maturity of 85 days from seeding to silking. The corn was planted in late May, 1968 at a row spacing of 50 cm and a population rate of 74,000 plants/hm^2. Harvest date was October 3, 1968.

Beaty, E.R., Robert L. Stanley and John Powell. Effect of cut on yield of Pensacola bahiagrass. Agron. J. 60:356-358. 1968.

In a two-year clipping study conducted in Americus, Georgia, the maximum dry matter yield of Pensacola bahiagrass (Paspalum notatum, var. saurae

Parodi) was 6.7 t/hm^2·yr. All grass was cut at monthly intervals from June 1 to October 1 and the optimum clipping height was 0-2.54 cm.

Beuerlein, James E., Henry A. Fribourg and Frank F. Bell. Effects of environment and cutting on the regrowth of a sorghum-sudangrass hybrid. Crop Sci. 8(2):152-155. 1968.

Sudangrass, adapted to almost every state, produced a maximum yield of 18.4 t of dry matter/hm^2 in Knoxville, Tennessee. The grass was planted June 20, emerged July 11 and was harvested September 12. Meteorological data is given for the duration of the experiment.

Bryant, H.T. and R.E. Blaser. Plant constituents of an early and a late corn hybrid as affected by row spacing and plant population. Agron. J. 60:557-559. 1968.

The maximum dry matter yield of corn harvested at late dent in Virginia during 1964 and 1965 was 14.8 t of silage/hm^2·yr and 7.4 t of grain/hm^2·yr. The maximum yielding variety was Pioneer 309A, a late-maturing hybrid which was planted at the rate of 98,800 plants/hm^2 in rows with 71 cm spacing.

Burnside, O.C. and G.A. Wicks. Influence of weed competition on sorghum growth. Weed Sci. 17(3):332-334. 1969.

Sorghum was planted May 20, 1967 in Lincoln, Nebraska at different population levels and row spacings and subjected to different weed removal treatments. The maximum oven-dry weed yield was 3.8 t/hm^2·yr when sorghum, planted at 64,220 plants/hm^2 in 102 cm rows, was not treated for weeds. Under the same conditions 1.3 t/hm^2 of dried sorghum grain and 1.3 t/hm^2 of dried sorghum stovers were obtained. The maximum grain and stover yields were 4.8 and 3.5 t/hm^2 respectively, for sorghum planted at 123,500 plants/hm^2 in 51 cm rows. The corresponding weed yield was 0.1 t/hm^2.

Burnside, O.C. and G.A. Wicks. The effect of weed removal treatments on sorghum growth. Weeds 15(3):204-207. 1967.

The oven-dry yield of weeds from sorghum plots which were not treated with herbicide was 1.0 t/hm^2. In treated plots, the maximum oven-dry yield of sorghum grain and stovers was 4.0 and 4.8 t/hm^2 respectively. Major weed species encountered were smooth pigweed (Amaranthus hybridus L.), foxtail (Setaria spp.) and crabgrass (Digitaria spp.). The experiments were conducted in Lincoln, Nebraska.

Cara-Costas, Ruben. Effect of plant population and distribution on yields of plaintains. J. of Agric., Univ. of P.R. 52(3):256-259. 1968.

Experiments on plaintain were conducted at Orocovis, Puerto Rico, a humid tropical region where mean annual temperature is 23.9°C and annual rainfall averages 160 cm. Fresh weight yields of fruit increased from 12.2 to 21.4 $t/hm^2 \cdot yr$ (4.1 - 7.2 t dry matter/$hm^2 \cdot yr$ assuming 66.4% moisture) with a change in population from 1235 to 1976 plants/hm^2.

Crop management. Successful Farming. May, 1974. p. 11.

Maximum corn yield of a Firth, Nebraska farmer was 15.0 t/hm^2 (12.8 t dry matter/$hm^2 \cdot yr$ assuming 15% moisture) in 1972. The corn was irrigated and final stand count was 61,750 plants/hm^2. Yields averaged over 12.6 $t/hm^2 \cdot yr$ (10.7 t dry matter/$hm^2 \cdot yr$ assuming 15% moisture) during a five-year period.

Doss, B.D. Comparison of fog irrigation with surface irrigation in corn production. Agron. J. 66(1):105-107. 1974.

The effects of fog and surface irrigation on variety Funk G-5757 corn were compared in Thorsby, Alabama. The corn, planted between April 7 and 9 yearly, was adequately fertilized and thinned to 65,000 plants/hm^2. Maximum yields were as follows: 10.4 t dry matter/hm^2 for stovers with surface irrigation only, 8.2 t/hm^2 for grain (0% moisture) with both fog and surface irrigation, and 20 t dry matter/hm^2 for the total yield of grain and stovers with both fog and surface irrigation.

Edwards, Ned C., Jr., Henry A. Fribourg and M.J. Montgomery. Cutting management effects on growth rate and dry matter digestibility of the sorghum-sudangrass cultivar Sudax SX-11. Agron. J. 63(2):267-270. 1971.

The maximum dry matter yield of sorghum-sudangrass cultivar Sudax SX-11 in Knoxville, Tennessee was 20 $t/hm^2 \cdot yr$. The grass was cut once at the early boot stage to a height of 15 cm. Average rainfall in Knoxville is 515 mm.

Enyi, B.A.C. Effect of staking, nitrogen, and potassium on growth and development in lesser yams. Ann. Appl. Biol. 72(2):211-219. 1972.

In Sierra Leone, the yield of yam tubers from staked plants averaged 20.3 t dry matter/hm^2 or about 56% of the total dry weight. The yams were planted in April and harvested in December.

Einspahr, Dean W. Wood and fiber production from short rotation stands. In: Aspen Symposium Proceedings. USDA Forest Service Gen. Tech. Rep. NC-1. 1972.

Aspen, especially quaking aspen, is widely distributed. It has vigorous root sucker production and develops into densely stocked stands of trees with good straightness, good natural pruning and narrow crowns. The two Lake States aspens, bigtooth (*Populus tremloides*) and quaking (*P. grandidentata*) can occupy a site within 2-3 years after cutting. Annual growth rates of 0.7 and 3.0 t dry matter/hm^2 (based on 25 and 106 ft^3/acre and assuming 25 lb/ft^3) have been reported for undamaged six and thirteen year old sucker stands in Wisconsin and Manitoba, respectively. There were 35,724 trees/hm^2 in the six year old stand and 19,674 trees/hm^2 in the thirteen year old stand. Annual growth rates up to 5.5 t dry matter/hm^2 (based on 198 ft^3/acre and assuming 25 lb/ft^3) have been reported for thirteen year old triploid hybrid aspen in northern Wisconsin. There were 1329 trees/hm^2 at a spacing of 2.74 x 2.74 m. Yields of first rotation suckers have been up to 30% higher than yields from original plantings.

Follett, R.F., E.J. Doering, G.A. Reichman and L.C. Benz. Effect of irrigation and water table depth on crop yields. Agron. J. 66(2):304-308. 1974.

Two-year average dry matter yields of corn grain, corn silage, and sugarbeets (oven-dried roots, tops and crowns) in eastern North Dakota were 3.8 - 7.1 t/$hm^2 \cdot$yr, 7.5 - 14.8 t/$hm^2 \cdot$yr and 7.8 - 19.3 t/hm^2 respectively. The maximum alfalfa yield when cut three times in one year was approximately 10.1 t dry matter/$hm^2 \cdot$yr. The data showed that shallow water tables can produce maximum yields without irrigation.

Fuess, F.W., and M.B. Tesar. Photosynthetic efficiency, yields and leaf loss in alfalfa. Crop Sci. 8(2):159-163. 1968.

Plots of alfalfa (*Medicago sativa*) at the Michigan State University Farm were subjected to one, two, three or four cuttings prior to September. Three cuttings provided the maximum hay yield of 10.6 t dry matter/$hm^2 \cdot$yr.

Genter, C.F. and H.M. Camper. Component plant part development in maize as affected by hybrids and population density. Agron. J. 65(4):669-671. 1973.

At Warsaw, Virginia, six maize hybrids, representing three maturity classes were planted at four population densities over a three-year period. Annually, the maize received 165 kg N, 55 kg P and 104 kg K/hm^2. DeKalb

805, a mid-season variety gave a maximum total dry yield (stovers and grain) of 16.5 t/hm^2 when planted at the rate of 64,000 plants/hm^2. The maximum grain yield of 6.9 t dry matter/hm^2·yr was obtained with the same variety planted at the rate of 44,500 plants/hm^2.

Heilman, P.E., D.V. Peabody, Jr., D.S. DeBell and R.F. Strand. A test of close-spaced, short-rotation culture of black cottonwood. Can. J. For. Res. 2(4):456-459. 1972. [Abstract].

The average fresh weight production by black cottonwood (*Populus trichocarpa* Torr. and Gray) grown under a two-year rotation schedule at various spacings was 13.4 t/hm^2·yr (4.7 t dry matter/hm^2·yr assuming 65% moisture) for the first rotation and 20.9 t/hm^2·yr (7.3 t dry matter/hm^2·yr assuming 65% moisture) for the second.

High yields turned out with reduced tillage. No Till Farmer. Late Planting Issue. April 1974.

The maximum dryland corn yield from eight states was 14.0 t/hm^2·yr (11.9 t dry matter/hm^2·yr assuming 15% moisture) with conventional tillage in Milton, Pennsylvania. Yields with no tillage were in the vicinity of 12.6 t/hm^2·yr (10.7 t dry matter/hm^2·yr assuming 15% moisture). The top irrigated yield was 16.8 t/hm^2·yr (14.3 t dry matter/hm^2·yr assuming 15% moisture) in California.

Hoveland, C.S. and W.B. Anthony. Cutting management of syricea lespedeza for forage and seed. Agron. J. 66(2):189-191. 1974.

In Alabama, the maximum forage yield of syricea lespedeza (*Lespedeza cureata* [Dumont] G. Don) var. Serala, was over 9.0 t of dry matter/hm^2·yr. Harvests were at nine-week intervals beginning April 21 and ending in either August or October.

Humphries, E.C. and S.A.W. French. Photosynthesis in sugar beets depends on root growth. Planta (Berl.) 88:87-90. 1969.

Sugarbeets which were germinated in the greenhouse and transplanted developed larger roots than sugarbeets seeded directly in the soil. The larger roots provided a larger carbohydrate sink allowing for greater photosynthesis. The fresh beet yield of the transplants was 57.5 t/hm^2 (9.4 t dry matter/hm^2·yr assuming 83.6% moisture).

Martin, Franklin W. Tropical Yams and Their Potential. Part I. Dioscorea esculenta. ARS-USDA in cooperation with US Agency for International Development. Agric. Handbook No. 457. April, 1974.

The lesser yam (Dioscorea esculenta), well-known in the tropics, can grow almost year round. The maximum reported yield was 55 t of fresh yams/$hm^2 \cdot$ yr (14.6 t dry matter/$hm^2 \cdot$yr assuming 73.5% moisture) at the Federal Experiment Station in Mayaguez, Puerto Rico when yams of 135 grams each were planted at spacings of 60x60 cm.

Mislevy, P., J.B. Washko and J.E. Harrington. Effects of different initial cutting treatments on the production and quality of climax timothy and reed canarygrass. Agron. J. 66(1):110-112. 1974.

In experiments at State College, Pennsylvania, timothy and reed canarygrass were initially cut at eight physiological stages of development corresponding to heights of 20 to 81 cm and then cut three more times at seven-week intervals. The maximum dry matter yields were 10.0 t/hm^2 for timothy cut initially at 30 cm and 10.3 t/hm^2 for reed canarygrass cut at 81 cm.

Parsons, J.L. and R.R. Davis. Forage production of vernal alfalfa under differential cutting and phosphorus fertilization. Agron. J. 52:441-443. 1960.

In experiments at Wooster, Ohio, the maximum dry matter yield of alfalfa was 10.4 t/hm^2 in 1958 when the crop was cut three times at 45-day intervals from June through September. Phosphorus fertility was high in the maximum yield plot.

Patel, B.M., C.A. Patel and B.M. Dhami. Effect of different cutting intervals on the dry matter and nutrient yield of napier grass. Ind. J. of Agric. Sci. 37(5):404-409. 1967.

The maximum dry matter yield of napier hybrid grass in experiments at Poona, India was 57.1 t/hm^2 for 600 days. The grass was cut every 60 days.

Pendleton, J.W. and D.B. Egli. Potential yield of corn as affected by planting date. Agron. J. 61(1):70-71. 1969.

At Urbana, Illinois, two high-yielding varieties of corn were planted on different dates and yields were determined. High management and fertility levels and adequate soil moisture were maintained. Total N application was 336 kg/hm^2. Sowing dates were April 5 for corn sown in the greenhouse and transplanted and April 19, April 30, May 14 and May 31 for corn sown in the field. Maximum grain yields were 11.5 t dry matter/$hm^2 \cdot yr$ for var. PAG SX29 sown April 19 and 10.1 t dry matter/$hm^2 \cdot yr$ for variety DeKalb XL45 sown April 30.

Schreiner, Ernest J. Mini-rotation forestry. USDA Forest Service Res. Paper NE-174. 1970.

One aspect of mini-rotation forestry involves the production of fiber using 2 to 5 year rotation cycles. Numerous hardwood and coniferous species which could be used in short-rotation trials in the Northeast are described. In Maine, a four-year-old stand of hybrid poplars (Populus) at spacings of 30 x 122 cm (1x4 ft.) produced approximately 10.5 t/hm^2 of oven-dry peeled stem-wood and branches with bark. In Pennsylvania, a 3-year old stand of hybrid poplars at spacings of 15 x 61 cm (1/2 x 2 ft.) produced 5.4 t/hm^2 of oven-dry peeled stem-wood. Some economic considerations of mini-rotation forestry are discussed.

Stibbe, E. and U. Kafkafi. Influence of tillage depths and P-fertilizer application rates on the yields of annual cropped winter-grown wheat. Agron. J. 65(4):617-620. 1973.

The maximum dry matter production of wheat (grain and straw) grown at two Israeli locations in 1968-70 was 24.0 t/$hm^2 \cdot 2$ years. Rainfall was 336 and 177 mm for 1968-69 and 1969-70, respectively, and 180 mm of irrigation water was applied in 1970.

Terman, G.L. Variability in grass forage clipping experiments comparing fertilizer rates and sources. Agron. J. 64(1):20-23. 1972.

Yields of dry bermudagrass forage at Muscle Shoals, Alabama ranged from 1.9 to 19.5 t/$hm^2 \cdot yr$ when cut four times yearly for three years. Nitrogen rates ranged from 0 to 896 kg/hm^2. Three cuttings in a two-year stand of tall fescue brought yields of 2.5 to 8.3 t/hm^2 during 1966, with nitrogen rates of 0 to 168 kg/hm^2. The 1966 range of dry hybrid sorghum yields was 4.8 to 8.6 t/$hm^2 \cdot yr$ with nitrogen treatments of 0 to 224 kg/hm^2 and five cuttings.

Vincente-Chandler, José, Servando Silva, José Rodriguez and Fernando Abruña. Effects of two heights and three intervals of grazing on the productivity of a heavily fertilized pangola grass pasture. J. of Agric. Univ. of P.R. 56(2):110-114. 1972.

Pangola grass was grown in the humid tropical mountains of Puerto Rico where rainfall averages 191 cm (75 inches)/yr. When grazed to a height of 15 cm (6 inches) every 14 days, the yield of dry forage was 16.0 $t/hm^2 \cdot yr$.

Werner, Joaquim Carlos, Fausto Pereira Lima, Dinival Martinelli and Benjamin Cintra. Estudo de tres diferentes alturas de corte em capim elefante Napier. (Study of three cutting heights on napier grass (*Pennisetum pupureum*) Schum. Bot. Ind. Anim. 23:161-168. 1965/66. [Abstract].

Low (1-3 cm), medium (30-40 cm) and high (70-80 cm) cutting heights were used at four week intervals for 17 cuttings. Dry matter yields of napier grass were 4.5, 11.2 and 13.1 $t/hm^2 \cdot 68$ weeks, respectively, for low, medium and high cutting heights. Differences in yields were insignificant between medium and high cutting heights, but between these two (medium and high) and the low cutting height differences were highly significant.

Whitaker, F.D., H.G. Heinemann and W.E. Larson. Plant population and row spacing influence maximum corn yield. Mo. Agric. Exp. Sta. Res. Bull. 961. 1969.

Corn was grown in Ellsberry, Missouri during 1965-66. Soil, water availability and management practices were excellent, but climatic conditions were unfavorable for maximum corn yields. In 1965, the total maximum yield of dry matter (grain and forage) was 20.4 $t/hm^2 \cdot yr$, attained with United Hagie 152 planted at 69,160 $plants/hm^2$ in 76 cm (30 inch) rows. With similar spacing and plant population, Pioneer 321 corn gave the 1966 maximum yield of 20.6 $t/hm^2 \cdot yr$.

White, G.A., W.C. Adamson and J.J. Higgins. Effect of population levels on growth factors in kenaf varieties. Agron. J. 63(2):233-235. 1971.

Of seven kenaf (*Hibiscus cannabinus* L.) varieties planted in Glen Dale, Maryland and Savannah, Georgia, the maximum yield of dry matter was 13.5 $t/hm^2 \cdot yr$ with variety SH-15R at Glen Dale. Plant population was 296,000 $plants/hm^2$.

Wicks, G.A., D.N. Johnston, D.S. Nuland and E.J. Kinbacher. Competition between annual weeds and sweet Spanish onions. Weed Sci. 21(5):436-439. 1973.

The major weed species found in Spanish onions (*Allium cepa* L.) in North Platte, Nebraska were redroot pigweed (*Amaranthus retroflexus* L.), kochia (*Kochia scoparia* L.) and several grass weeds. The maximum yield of oven-dry weeds was 12.0 t/hm^2 for plots which were either not treated for weed removal or not treated until the end of emergence. The maximum onion yield was 0.8 t of dry top growth/hm^2 and 43 t/hm^2 (4.7 t dry matter/hm^2·yr assuming 89% moisture) of bulbs which were air-cured for one week.

Wiese, Allen F., E. Wayne Chenault and Dale Hollingsworth. Preplant application of herbicides for weed control in grain sorghum. Agron. J. 65(4): 583-586. 1973.

Field trials were conducted at three Texas locations, Bushland, Pantex and a farm near Dumas, during 1965-70 to test for the controlling effects of preplant applications of herbicides on piggrass (Amaranthus spp.) and barnyard grass (Echinochloa crusgalli L. Beauv.) in grain sorghum. With herbicide treatment, sorghum yields were as high as 6.8 t of grain/hm^2 (6.05 t dry matter/hm^2·yr assuming 11% moisture) while untreated sorghum produced only 0.18 t/hm^2·yr (0.17 t dry matter/hm^2·yr assuming 11% moisture).

Worker, George F., Jr. Sudangrass and sudangrass hybrids responses to row spacing and plant maturity on yields and chemical composition. Agron. J. 65(6):975-977. 1973.

Three summer annuals were planted in the desert area of El Centro, California where the growing season is approximately 224 days, and annual rainfall averaged 4.8 cm (1.9 inches) during the experiment. The grasses were planted at different row spacings, were fertilized and irrigated and harvested at either the flower or the pasture stage. Maximum dry matter yields were as follows: 31.1 t/hm^2·yr for sudangrass (Sorghum sudanese [Piper] Stapf.), 33.7 t/hm^2·yr for sudangrass hybrid var. Trudan 1, and 31.7 t/hm^2·yr for sorghum-sudangrass (Sorghum bicolor L. Moench x Sorghum sudanese Piper Stapf.) var. Sudax SX-11. All maximum yields were from plots which had row spacings of 35.6 cm and which were harvested at the pasture stage.

Yates, R.D. Assessment of the effect of intercane variability on the sampling and harvesting of sugarcane. Agron. J. 61(1):113-116. 1969.

In the Puerto Rican experiments, a summer-planted gran cultura sugarcane crop produced a maximum of 218 t/hm^2 (50.6 t dry matter/hm^2 assuming 76.8% moisture) when harvested at 19 months of age. The maximum yield of the spring planted primavera crop was 121 t/hm^2 (23.1 t dry matter/hm^2 assuming 76.8% moisture) when harvested at 12.5 months of age. Ratoon crops grown from the stubble of a previous crop produced a maximum of 108 t/hm^2 (25.1 t dry matter/hm^2 assuming 76.8% moisture) at 14.25 months of age.

1972 Report-Farming Systems Program. International Institute of Tropical Agriculture. Ibadan, Nigeria.

The 9-month dry matter yield of guinea grass in Nigeria was 30 t/hm^2 when cut 3 times at 3-month intervals. An additional 16 t/hm^2 of natural regrowth occurred in the following eight months with only 1 cutting. No fertilizer was applied.

INPUT/OUTPUT DATA

Adams, William E., A.W. White, R.A. McCreery and R.N. Dawson. Coastal bermudagrass forage production and chemical composition as influenced by potassium source, rate and frequency of application. Agron. J. 59:247-250. 1967.

Coastal bermudagrass, one of the principal pasture crops of the southern piedmont plateau, produced 16.9 t/hm^2 of oven-dry forage (three-year average, 1961-1963) with the application of 750 kg/hm^2 of potassium as sulfate of potash applied entirely on April 1. In addition, the grass received an annual treatment of 897 kg/hm^2 of nitrogen applied in four equal applications.

Angus, J.F., R. Jones and J.H. Wilson. A comparison of barley cultivars with different leaf inclinations. Aust. J. Agric. Res. 23(6):945-957. 1972.

The total dry matter yield of 'Lenta' barley (Hordeum distichum L.) in Mount Derrimut, Australia was 10 t/hm^2. The barley was sown at a high density on July 7 and harvested on December 17, 1969. 280 kg/hm^2 of N-P-K fertilizer (8-24-12) was applied and there was no irrigation. The 'Lenta' variety has short, erect leaves.

Burton, Glen W., W.S. Wilkinson and R.L. Carter. Effect of nitrogen, phosphorus and potassium levels and clipping frequency on the forage yield and protein, carotene and xanthophyll content of coastal bermudagrass. Agron. J. 61(1):60-63. 1969.

Coastal bermudagrass in Tifton, Georgia produced a maximum of 24.2 t dry matter/hm^2·yr when cut at 6-week intervals and treated with 1,008 kg N/hm^2 applied over a period of four dates beginning in April.

Campbell, R.E. and F.G. Viets, Jr. Yield and sugar production by sugar beets as affected by leaf area variations induced by stand density and nitrogen fertilization. Agron. J. 59:349-354. 1967.

Sugar beets were planted on April 2 in Huntley, Montana (45°45'N) at three different spacings and fertilized with four different nitrogen rates. The maximum total (roots and tops) dry matter yield at the October harvest was 20.7 t/hm^2. Optimum treatments were 45.7 cm row spacing and 336 kg N/hm^2 applied on April 2 plus 224 kg N/hm^2 applied on August 15. LAI at harvest was 5.2. The maximum dry matter yield of roots alone was 10.4 t/hm^2 and the maximum yield of tops alone was 11.9 t/hm^2.

Capiel, Modesto, and Gaylen L. Ashcroft. Effect of irrigation, harvest interval and nitrogen on the yield and nutrient composition of napiergrass (Pennisetum purpureum). Agron. J. 64(3):396-399. 1972.

The effect of two harvest intervals, two irrigation rates and two nitrogen rates on napier grass were measured. The work was conducted at Gurabo, Puerto Rico, where mean annual rainfall is 160 cm and mean annual temperature is 25°C. The maximum yield of dry matter was 48.5 t/hm^2·yr. The grass was irrigated, treated with 1120 kg N/hm^2 and harvested at 60-day intervals.

Cara-Costas, Ruben, Fernando Abrũna and Jacinto Figarella. Effect of nitrogen rates, harvest interval and cutting heights on yields and composition of star grass in Puerto Rico. J. of Agric. Univ. of P.R. 56(3):267-269. 1972.

Stargrass (Cynodon dactylon) was grown for two consecutive years at Orocovis, Puerto Rico. Mean annual temperature was 21.1°C (70°F) and average rainfall was 173 cm (68 inches)/year. Maximum dry matter yield was 37.3 t/hm^2·yr with the following treatments: 890 kg N/hm^2, a 90 day harvest interval and a 5 cm (2 inch) cutting height.

Carter, J.N., M.E. Jensen and S.M. Bosma. Determining nitrogen fertilizer needs for sugarbeets from residual soil nitrate and mineralizable nitrogen. Agron. J. 66(2):319-323. 1974.

Sugar beets were grown during two consecutive years at Twin Falls, Idaho, at 14 residual and fertilizer nitrogen rates. A potato fertility study conducted a year prior to the sugar beet study provided the residual nitrogen. The production of a tonne of fresh beets requires from 4.38 to 6.00 kg of nitrogen depending upon climate, location, water availability and other factors. The maximum yield of fresh roots was 61.4 t/hm^2 (10.1 t dry matter/hm^2·yr assuming 83.6% moisture) during the second year of the experiment. The plot had been treated with 360 kg N/hm^2 during the potato experiment and 112 and 56 kg/hm^2 during the first and second year of the sugar beet experiment, respectively. The beets were planted April 21 at 60 cm spacing and thinned to 30 cm row spacing.

Chew, Wee Yong. Yield and growth responses of some leguminous and root crops grown on acid peat to magnesium lime. Malaysian Agric. J. 48(2):142-158. 1971.

The maximum yield of sweet potato tubers in Malaysian experiments was 15.0 t fresh weight/hm^2·yr (4.8 t dry matter/hm^2·yr assuming 69.2% moisture) with a treatment of 16.8 t magnesium lime/hm^2. The accompanying vine yield was 5.8 t fresh weight/hm^2·yr (1 t dry matter/hm^2·yr assuming 82.2% moisture). The maximum vine yield was 13.1 t fresh weight/hm^2·yr (2.33 t dry matter/hm^2·yr assuming 82.2% moisture) when treated with 17.9 t magnesium/hm^2·yr. The maximum yield of tapioca tubers, which showed no positive yield response to magnesium lime, was 22.7 t fresh weight/hm^2·yr, (7.3 t dry matter assuming 68% moisture). Additional production factors are included for these and other crops.

Chin, Nyeok Yoon. Sources of nitrogen on the growth and yield of sugar cane. Malaysian Agric. J. 48(1):69-76. 1971.

Maximum mean yields of canes in Malaysia from an original planting and from the first ratoon crop were 13.2 - 14.9 t dry matter/hm^2·yr (based on 25.47 and 28.75 tons fresh weight/acre·yr and assuming 76.8% moisture) respectively. Plots recieved 74.0 kg N/hm^2 in the form of either sulphate of ammonia, urea or ammonium nitrate. There were no significant differences in yield attributed to the three sources of nitrogen.

Chin, Nyeok Yoon and Chua Ang Kok. Effect of nitrogen on the growth and yield of three clones of sugarcane. II. The ratoons. Malaysian Agric. J. 47(4):429-435. 1970.

The highest yield of canes for 2 ratoon crops fertilized with four different nitrogen rates was 17.2 t dry matter/hm^2·yr (based on 33.11 tons fresh cane/acre·yr and assuming 76.8% moisture), for the first ratoon crop. The maximum yield was obtained with clone No. Co. 310 which received 85.1 kg N/hm^2.

Donahue, S.J., C.L. Rhykerd, D.A. Holt and C.H. Noller. Influence of N fertilization, and N carry over on yield and N concentration of *Dactylis glomerata* L. Agron. J. 65:671-674. 1973.

At the Normandy Farm near Indianapolis, Indiana, the maximum dry matter yield of orchardgrass during several years of experiments was 15.5 t/hm^2·yr in 1968. In this year, 672 kg N/hm^2 was applied and moisture was favorable.

Gonske, R.G. and D.R. Keeney. Effect of fertilizer nitrogen, variety and maturity on the yield and nitrogen fractions of corn grown for silage. Agron. J. 61(1):72-76. 1969.

In the marginal corn producing area of Spooner, Wisconsin, where the growing season is approximately 120 days, three early maturity varieties of corn were treated with one of four nitrogen rates. Plant populations were 64,200 and 44,600 plants/hm^2 for irrigated and non-irrigated plots, respectively. The maximum dry yield was 20.6 t/hm^2 for variety 273 which was fertilized with 100 kg N/hm^2, irrigated and harvested at late dent.

Figarella, Jacinto, Fernando Abrũna and Josê Vincente-Chandler. Effect of five nitrogen sources applied at four rates to pangola grass sod under humid tropical conditions. J. of Agric., Univ. of P.R. 56(4):410-416. 1972.

Ammonium sulphate and urea were respectively, the most and least efficient sources of nitrogen applied to pangola grass in tropical Puerto Rico. A maximum dry matter yield of 21.29 t/hm^2 was obtained with the application of 570 kg N/hm^2·yr.

Fuehring, H.D. Effect of anti-transpirants on yield of grain sorghum under limited irrigation. Agron. J. 65(3):348-351. 1973.

Anti-transpirants were applied to drought-resistant grain sorghum (<u>Sorghum bicolor</u> L. Moench) in the southern high plains of New Mexico. A maximum grain yield of 7.4 t/hm^2 (6.6 t dry matter/hm^2·Yr assuming 11% moisture) was attained in 1970 when grain sorghum, planted May 14, was irrigated four times and treated with 45 grams of phenylmercuric acetate (PMA) on July 14.

Hucklesby, D.P., C.M. Brown, S.E. Howell and R.H. Hageman. Late spring application of nitrogen for efficient utilization and enhanced production of grain and grain protein of wheat. Agron. J. 63(2):274-276. 1971.

Of three winter wheat varieties planted in Illinois, 'Blueboy' produced the maximum grain yield of 6.4 t/hm^2 (5.6 t dry matter/hm^2·yr assuming 13% moisture). The wheat was treated with 112 kg N/hm^2 on May 9.

Klebesadel, L.J. Agronomic characteristics of the little-known, northern grass (<u>Arctagrostic latifolia</u>) var. arundinacia (Trin.) Griseb., and a proposed common name, tall arcticgrass. Agron. J. 71(1):45-49. 1969.

Tall arcticgrass, a tall-growing perennial, and polar bromegrass were planted in Alaska in June 1963. Both grasses were fertilized with nitrogen and cut at two week intervals throughout a two year period. Two-year means of season totals of dry matter were 9.7 and 10.2 t/hm^2 for tall arcticgrass and polar bromegrass, respectively.

Monson, Warren G. Effects of burning on soil temperature and yield of coastal bermudagrass. Agron. J. 66(2):212-214. 1974.

The maximum yield of coastal bermudagrass during 6 years of experiments was 17.8 t/hm^2·yr in 1966. The plot was burned March 1 and 672 kg/hm^2 of N was applied. Harvesting was at 21-day intervals.

Prabhakaran Nair, K.P., and R.P. Singh. Correlative analysis of yield and its components in maize. Expl. Agric. 10:81-86. 1974.

The maximum mean grain yield of maize was 4.1 t dry matter/hm^2·yr with variety Ganja 2 at Pantnagar, India (29°N79.3°E). The altitude at Pantnagar is 244 m, rainfall is high and average maximum and minimum temperatures are 32 and 25°C, respectively. Yields increased with increasing N up to the maximum rate applied, 150 kg/hm^2.

Sanchez, P.A., G.E. Ramirez and M.V. deCalderon. Rice responses to nitrogen under high solar radiation and intermittent flooding in Peru. Agron. J. 65(4):523-529. 1974.

During the 1969-70 growing season at the Lambayoque Experimental Farm (6°42'S) in Peru, a maximum rice (Oryza sativa L.) grain yield of 10.1 t dry matter/hm^2·yr was obtained with IR8, an early-maturing, semi-dwarf variety. The total dry matter yield (grain plus straw) was approximately 20 t/hm^2. Treatments were intermittent flooding and 480 kg N/hm^2.

Schnappinger, M.G., Jr., D.C. Martens, G.W. Hawkins, D.F. Amos and G.D. McCart. Response of corn to residual and applied zinc as $ZnSO_4$ and Zn-EDTA in field investigations. Agron. J. 64(1):64-66. 1972.

Experiments were carried out on zinc deficient soils in the Allegheny mountains. In two years of experimentation on Litz clay loam soil, a maximum grain yield of 5.7 t dry matter/hm^2·yr was obtained with the application of 28 kg Zn/hm^2 during the second year. In one year of experimentation on Westmoreland silty clay loam, the maximum yield was 8.3 t dry matter/hm^2·yr with a 27.2 kg/hm^2 application of zinc. In both cases, zinc was applied as $ZnSO_4$.

Seetanum, W. and S.K. DeDatta. Grain yield, milling quality and seed viability of rice as influenced by time of nitrogen application and time of harvest. Agron. J. 65(3):390-394. 1973.

During the 1970 dry season at the International Rice Research Institute at Los Banos, Phillippines, the maximum yield of rice grain was 5.8 t dry matter/$hm^2 \cdot yr$ with cultivar RD1 (average of 15 harvest dates). Rice was treated with a total of 150 kg N/hm^2, one-half applied as a basal application and one-half at panicle initiation.

Thorne, Gillian and D.J. Watson. The effect on yield and leaf area of wheat of applying nitrogen as a top-dressing in April or in sprays at ear emergence. J. Agric. Sci. 46:449-456. 1955.

Yeoman wheat was grown at the Rothamsted farm in Harpenden, Herts., Britain. Maximum dry matter yields (straw, grain and chaff) were 9.5 and 10.4 t/$hm^2 \cdot yr$ during 1952 and 1953, respectively. The 1952 yield was attained when a total of 63 kg N/hm^2 was applied to the soil during May and June. In 1953, 63 kg N/hm^2 was applied as a top-dressing in April and an additional 63 kg N/hm^2 was applied to the soil during May and June.

Turton, A.G. and J. Keay. Changes in dry weight and nutrient distribution in maritime pine after fertilization. Austral. Forestry 34(2):84-96. 1970.

The dry weight of a 13-year old pine stand increased from 28.8 to 52.6 t/hm^2 in three years after applying 206 kg N/hm^2 and 90 kg P/hm^2. The stand density was approximately 1800 trees/hm^2.

Tweedy, J.A., A.D. Kern, G. Kapusta and D.E. Millis. Yield and nitrogen content of wheat and sorghum treated with different rates of nitrogen fertilizer and herbicides. Agron. J. 63(2):216-218. 1971.

In Belleville, Illinois the maximum yield of wheat grain was 3.2 t/$hm^2 \cdot yr$ (2.8 t dry matter/$hm^2 \cdot yr$ assuming 13% moisture) and the maximum sorghum grain yield was 8.0 t/$hm^2 \cdot yr$ (7.1 t dry matter/$hm^2 \cdot yr$ assuming 11% moisture). The wheat was treated with 70 kg N/hm^2 and 0.28 kg atrazine/hm^2. The sorghum was treated with 112 kg N/hm^2, but received no herbicide treatment.

Vincente-Chandler, José, Servando Silva, Fernando Abrũna and José Rodriguez. Effect of two cutting heights, four harvest intervals and five nitrogen rates on yield and composition of congo grass under humid tropical conditions. J. of Agric., Univ. of P.R. 56(3):280-291. 1972.

Congo grass was grown and harvested under various schemes in the humid tropical mountains of Puerto Rico. Temperatures ranged from 17.8 - 31.7° C (64-89°F) and rainfall averaged 192 cm during the two years of experimentation. The maximum dry matter yield of 50.7 t/hm^2·yr was attained by fertilizing at a rate of 670 kg N/hm^2, and cutting to a height of 5.1 cm every 90 days.

Watson, D.J., Gillian N. Thorne and S.A.W. French. Analysis of growth of winter and spring wheats. Annals of Bot. 27:1-22. 1963.

Of all spring and winter wheats planted at the Rothamsted farm in Harpenden, Herts., Britain, the winter variety, Capelle Desprez, produced the maximum yield of 12.9 t dry matter (straw, grain and chaff)/hm^2·yr at final harvest August 15, 1960. A total of 27.2 kg N/hm^2 was applied on March 20.

Welch, L.F., L.V. Boone, C.G. Chambliss, A.T. Christiansen, D.L. Mulvaney, M.G Oldham and J.W. Pendleton. Soybean yields with direct and residual nitrogen fertilization. Agron. J. 65(4):547-550. 1973.

The maximum soybean yield of 3.5 t dry matter/hm^2·yr occurred at Urbana, Illinois, in 1965 when the soybean crop, which followed oats was fertilized with 336 kg/hm^2 of nitrogen. Seedings were made in May.

Whitney, A.S. Growth of kikuyugrass (Pennisetum clandestinum) under clipping. I. Effects of nitrogen fertilization, cutting interval, and season on yields and forage characteristics. Agron. J. 66(2):281-287. 1974.

The maximum dry weight yield of kikuyugrass in the Hawaiian Islands was 35.3 t/hm^2·yr at Makawai. Nitrogen was applied at the rate of 874 kg/hm^2. Data on air temperature, soil temperature, solar radiation levels and other environmental factors is provided.

1972 Corn and grain sorghum performance tests. College of Agriculture/University of Georgia/Athens. Expt. Sta. Res. Report 149. January 1973.

The maximum corn grain yield reported was 13.7 t/hm^2·yr (11.7 t dry matter/hm^2·yr assuming 15% moisture) for Pioneer 515 planted at Blairsville, Georgia at 54,340 plants/hm^2. Pioneer 3030 gave the highest dry forage yield of 18.4 t/hm^2 when planted at Experiment, Georgia on April 19 and harvested on August 17. 670 kg/hm^2 of 5-10-15 fertilizer was applied before planting, and 140 kg/hm^2 was applied on May 17. The maximum grain sorghum yield was 9.0 t/hm^2 (8 t dry matter/hm^2·yr assuming 11% moisture) at Blairsville with the hybrid Excel 811-A. The maximum dry forage yield was 19.9 t/hm^2 (3-year average) for Pioneer 931, a tall hybrid which reaches a height of over 244 cm. The sorghum was planted on May 7 and harvested at the dough stage. 560-670 kg of 5-10-15 fertilizer/hm^2 and 110 kg of N as a side-dressing were applied.

MULTIPLE SPECIES PRODUCTION

Burnside, O.C. Influence of weeds on soybean harvesting losses with a combine. Weed Sci. 21(6):520-523. 1973.

The maximum oven-dry weed yield in Nebraska soybean fields which were neither cultivated nor treated with herbicide, was 4.7 t/hm^2·yr, while the soybean yield was 0.9 t/hm^2·yr. The weed crop, approximately 39% broadleaf and 61% grassy species, was primarily composed of the following species: tall waterhemp (_Amaranthus tuberculatos_ [Moq.] J. Sauer), green foxtail (_Setaria viridis_ [L.] Beauv.), large crabgrass (_Digitaria sanguinalis_ [L.] Scop.) and velvet leaf (_Abutilon theophrasiti_ Medic).

Cummins, D.G. Interplanting of corn, sorghum and soybeans for silage. Dept. of Agronomy Georgia Station, Experiment, Georgia. Res. Bull. 150. Dec. 1973.

The effects of interplanting of corn, soybeans and sorghum on silage yield in Georgia locations were studied. Corn alone produced 14.3 t of dry forage/hm^2·yr at Midville compared to 11.8 t/hm^2·yr for corn and soybeans interplanted. Interplanted sorghum and soybeans produced 14.3 t/hm^2 at Midville while sorghum alone produced only 13.6 t/hm^2. In Calhoun, interplanted corn and sorghum produced 15.0 t/hm^2, corn alone produced 14.7 t/hm^2 and sorghum alone produced 10.9 t/hm^2. Information on population, irrigation and fertilizer rates is included.

Jones, M.B., J.E. Street and W.A. Williams. Leaching and uptake of nitrogen applied to annual grass and clover-grass mixtures in lysimeters. Agron. J. 66(2):256-258. 1974.

The four-year mean oven-dry matter yield of a mixture of subclover (_Trifolium subterranean_ L.) and soft chess grass (_Bromus mollis_ L.) was 7.0 t/hm^2 without the addition of nitrogen. Location of growth was the annual grasslands of California, which are typically nitrogen deficient.

Patel, B.M., P.C. Shukla and B.J. Patel. Composition and yield of fodder when guinea grass alone is grown, and when lucerne is grown between its rows. Ind. J. Agric. Sci. 38(1):17-21. 1968.

Guinea grass (_Panicum maximum_) was grown alone and in combination with lucerne at the Institute of Agriculture, Anand, using a 1x1 m spacing plan. When grown alone, guinea grass yielded 13.7 t dry matter/hm^2 the first year and 22.4 t/hm^2 the second. When lucerne was planted between the rows of guinea grass in the winter, total dry matter yields were 16.7 and 23.1 $t/hm^2 \cdot yr$ for the first and second years, respectively.

Shukla, P.C., B.M. Dhami and B.M. Patel. Effect of different spacings and cutting intervals on the yield and composition of hybrid napier grown singly or in association with lucerne. Ind. J. Dairy Sci. 23(3):146-150. 1970.

Napier grass was planted at a spacing of 1.2 x 1.2 m and guar, a seasonal fodder was planted in between the rows of hybrid napier and lucern during the winter. Harvesting was at 50-day intervals. Dry matter yields after 600 days were as follows: 21.1 t of napier, 6.3 t of lucerne and 2.2 t of guar/hm^2. The maximum napier yield when grown singly was 22.5 $t/hm^2 \cdot$ 600 days. The grass was planted at a spacing of 0.6 x 0.6 m and was cut at 50-day intervals.

Siewerdt, Lotar, and Ethan C. Holt. Yield components and quality of siratro-klein grass association. Agron. J. 66(1):65-67. 1974.

At College Station, Texas, the tropical legume siratro (Phaseolus atropurpureus D.C.) was grown in association with kleingrass (Panicum coloratum L.), a perennial grass of tropical origins. Harvests were at three, five and seven-week intervals. Maximum dry matter yields were 5.5 t/hm^2 for kleingrass alone, 5.5 t/hm^2 for siratro alone, 7.0 t/hm^2 for siratro grown in association with kleingrass and 8.6 t/hm^2 for kleingrass alone plus nitrogen fertilizer. All maximum yields were harvested at seven-week intervals.

Singh, Kartan and Shri Mohan. A case study of the economics of multiple cropping in Delhi state. Agricultural Mechanization in Asia. 4(2):35-40. 1973.

The economics of crop rotation in the state of Delhi, India are discussed. A yield table for individual crops and complete rotation systems is given. The maximum yield of all rotation systems was 45.4 t of green fodder/$hm^2 \cdot$ yr (11.4 t dry matter/$hm^2 \cdot yr$ assuming 75% moisture) for a maize/wheat/cowpea rotation.

Whitney, A.C., Y. Kanehiro and G.D. Sherman. Nitrogen relationship of three tropical forage legumes in pure stands and in grass mixtures. Agron. J. 59:47-50. 1967.

Three legumes, Desmodium canum (kaimi), Centrosema pubescens (centro) and Desmodium intortum (intortum) were grown either alone or with pangola or napier grass in the rainforest climate of the Island of Hawaii. Maximum dry matter yields were 23.7 and 23.2 $t/hm^2 \cdot yr$ for the mixtures of intortum and pangola grass and intortum and napiergrass, respectively.

PHOTOSYNTHETIC EFFICIENCY

Björkman, Olle and Joseph Berry. High-efficiency photosynthesis. Sci. American 299(4):80. 1973.

The C_4 dual pathway of carbon dioxide fixation is compared to the conventional C_3 Calvin-Benson pathway. Plants with the C_4 pathway are sugarcane, corn, sorghum, certain pasture grasses and _Atriplex rosea_. The Amaranth family includes both C_3 and C_4 plants. One C_4 Amaranth, _Tidestromia oblongifolia_, thrives in the low, hot desert areas of southwestern United States.

Black, C.C., T.M. Chen and R.H. Brown. Biochemical basis for plant competition. Weed Sci. 17(3):338-344. 1969.

A hypothesis is presented for the competitive nature of some plants based on biochemical processes. Included are discussions of CO_2 compensation concentrations, photorespiration and reactions of photosynthesis to light intensity, temperature and CO_2 and O_2 concentrations. Tables of efficient and non-efficient plants are presented.

Chen, T.M., R.H. Brown and C.C. Black, Jr. CO_2 compensation concentration, rate of photosynthesis and carbonic anhydrase activity of plants. Weed Sci. 18(3):399-403. 1970.

The CO_2 compensation concentrations of several plants were used as the basis of their classification according to photosynthetic capacity. Generally, low CO_2 compensation concentrations accompanied high photosynthetic activity. Major monocot and dicot tribes which contain the majority of genera with low CO_2 compensation concentrations are listed and tables of CO_2 compensation concentrations of specific species are presented.

Chen, T.M., R.H. Brown and C.C. Black, Jr. Photosynthetic $^{14}CO_2$ fixation products and activities of enzymes related to photosynthesis in bermudagrass and other plants. Plant Physiol. 47:199-203. 1971.

Evidence for the existence of the C_4 pathway of CO_2 fixation in bermudagrass is presented.

El-Sharkawy, M.A., R.S. Loomis and W.A. Williams. Photosynthetic and respiratory exchanges of carbon dioxide by leaves of the grain amaranth. J. Appl. Ecol. 5:243-251. 1968.

The photosynthetic reactions of the dicot, Amaranthus edulis, to changes in illumination, CO_2 concentration and temperature were similar to those of tropical monocots including maize and sugarcane. Characteristically these monocots exhibit large growth and net assimilation rates.

Heichel, G.H. Comparative efficiency of energy use in crop production. The Conn. Agric. Expt. Sta. New Haven, Conn. Bull. 739. November 1973.

The energy input by different systems into crop production is compared with the caloric yield of the crops. Although photosynthesis could theoretically reach an efficiency of 12%, even in maize, one of the most efficient crops, the maximum efficiency is only around 3%. The ratio of energy input to output in modern agriculture is approximately 1:1.

Sheehy, J.E. and J.P. Cooper. Light interception, photosynthetic activity and crop growth rate in canopies of six temperate forage grasses. J. Appl. Ecol. 10:239-250. April 1973.

In experiments at the Welsh Plant Breeding Station, Aberystwyth, photosynthetic efficiencies of six temperate forage grasses ranged from 3.9% for timothy (5352) to 7.8% for tall fescue (5170). The grasses were grown during a period of high solar radiation and water and nutrients were non-limiting. Canopies with erect leaves were the most efficient.

Shibles, R.M. and C.R. Weber. Leaf area, solar radiation interception and dry matter production by soybeans. Crop Sci. 5:575-577. 1965.

In Iowa experiments, it was determined that the rate of dry matter production in soybeans is a linear function of the percent solar radiation intercepted which, in turn, is dependent on the leaf area index.

Wareing, P.F. and J.P. Cooper. Potential Crop Production. London. Heineman Educational Books Limited. 1971.

A potato crop in Great Britain produced up to 24.9 $t/hm^2 \cdot yr$ (5.3 t dry matter/$hm^2 \cdot yr$ assuming 78.9% moisture). Perennial ryegrass (variety BA6280) produced 29.0 $t/hm^2 \cdot yr$ of dry matter with a 3.7% efficiency of light energy conversion.

Williams, W.A., R.S. Loomis and C.R. Lepley. Vegetative growth of corn as affected by population density. II. Components of growth, net assimilation rate and leaf-area index. Crop Sci. 5:215-219. 1965.

In the present experiments, crop growth rate usually continued to increase with an increase in LAI, even up to an LAI of 18. No optimum LAI was found.

AUXILIARY INFORMATION

Bradley, Dennis P. and Frank E. Biltonen. Economic operability - factors affecting harvest and transport costs. In: Aspen Symposium Proceedings. USDA Forest Service. Gen. Tech. Rep. NC-1. 1972.

A method of relating harvest and transport costs to forest survey data is outlined.

Chin, Nyeok Yoon. Growth studies on sugarcane: II. Nutrient uptake. Malaysian Agric. J. 48(4):357-392. 1972.

The rate and quantity of nutrient uptake by various plant parts was determined for sugarcane. The information presented can aid in determining the amount of fertilizer needed and the best time of application. A 36.9 t sugarcane yield was estimated to contain the following quantities of nutrients: 43.0 kg N, 14.0 kg P_2O_5, 81.4 kg K_2O, 17.2 kg CaO and 25.8 kg MgO.

Clark, T.F. and I.A. Wolff. A search for new fiber crops. XI. Compositional characteristics of Illinois kenaf at several population densities and maturities. TAPPI 52(11):2111-2116. 1969.

Kenaf was planted in Peoria County, Illinois at population densities ranging from 43,966 to 368,030 plants/hm^2. Harvests were made between 90 and 138 days after seeding and up to 96 days after frost. Analyses of the physical components are presented.

Dargavel, J.B. Provisional tree weight tables for radiata pine. Austral. Forestry 34(2):131-140. 1970.

Estimates of the dry and fresh weights of components of radiata pine from 5 to 18 year old plantations are given. Provisional weight tables can be used to estimate plot yields. The information provided could be useful in the determination of required harvest equipment.

Distilling a better fuel solution. Industrial Research 16(6):33. 1974.

A study at the University of California, Berkeley, has shown that cellulose could provide a significant amount of energy. The development of a process which involves first the biochemical conversion of cellulose to glucose and then glucose to alcohol, may make alcohol usage economically feasible. The article maintains that it might be desirable to grow crops specifically for their energy potential.

Dunckleman, P.H., R.D. Breaux, H.P. Fanguy and R.J. Matherne. Registration of CP. 61-37 sugarcane. Crop Sci. 8(5):642. 1968.

C.P. 61-37 sugarcane, developed in Florida, gave high yields with two stubble crops. This late maturing variety, well adapted for machine harvesting is recommended for use in parts of Louisiana.

Evetts, L.L. and O.C. Burnside. Germination and seedling development of common milkweed and other species. Weed Sci. 20(4):371-378. 1972.

Evetts in 1971 estimated that common milkweed (Asclepias L.), which can reproduce by seeds or adventitious buds on roots, causes an average sorghum loss of 0.7 $t/hm^2 \cdot yr$. Included in the article is information on the factors affecting germination and seedling development of common milkweed, kochia (Kochia scoparia L. Schrad.), hemp dogbane (Apocynum cannabinum, L.), sunflower (Helianthus annus L.) and honeyvine milkweed (Ampelamus albidus [Nuff.] Britt.).

Evetts, L.L. and O.C. Burnside. Milkweed - persistent perennial that reduces yields. Farm, Ranch and Home Quarterly. Spring, 1973. University of Nebraska, College of Agriculture.

Milkweed, a hard-to-kill perennial which thrives in moist places, is stimulated by fertilizers used on agronomic crops. Seeds will germinate at temperatures between 14.4 and 35°C (58 and 95°F). Plants can spread up to 305 cm radially per year.

French, G.W. An evaluation of cost factors in the production and harvesting of potatoes. USDA-ARS. Production Research Report No. 98. 1967.

Costs of potato production and harvesting vary widely. A guide for estimating both fixed and operating costs is presented.

Heinz, Don. J. and Rokuru Urata. Registration of H 50-7209 sugarcane. Crop Sci. 8(5):642. 1968.

The raw sugar yield of H 50-7209 sugarcane, which is adapted to the warm, irrigated and semi-irrigated regions of the Hawaiian Islands, is approximately 40.3 t/hm^2 during a two-year period.

Kalna, Y.P. and A.N. Pathak. Quality and quantity factors of nutrition of hybrid corn. Pflanzennaehr Bodenkd. 130(2):108-117. 1971. [Abstract].

Hybrid corn varieties varied in uptake of N, P, and K. Generally, decreased yields accompanied low nutrition. A physiological imbalance between N and P caused decreased grain yields.

Limited tillage saves 25% of water and 50% of fuel. No Till Farmer. Late Planting Issue. April 1974.

Savings through limited tillage at the Southwestern Great Plains Research Center are estimated at 25 and 50% for water and fuel usage, respectively. At Bushland, Texas, less than 18.7 liters of fuel/hm^2 was used with no tillage compared to the normal 74.8 - 112.2 liters/hm^2 for tilling and seeding on irrigated land.

Miller, Dwight L. Fuel alcohol from wheat. Presented at the Seventh National Wheat Utilization Research Conference. Manhattan, Kansas. Nov. 3-5, 1971.

Fermentation alcohol is produced as a result of yeast action on starches and sugars in natural raw materials. The theoretical alcohol yield from a pound of starch is 0.258 kg, while the actual yield is only 90% of the theoretical. An estimate of the cost of conversion of wheat to alcohol is presented. Also given are the effects of wheat cost on the cost of ethyl alcohol.

Miller, Dwight L. Industrial alcohol from wheat. Presented at the Sixth National Wheat Utilization Research Conference. Oakland, Calif. Nov. 5-7, 1969.

The possible use of ethyl alcohol in motor fuels is discussed. Ethyl alcohol can be made from the fermentation of cereal grains, sugarcane, sugar beets, fruit product wastes, potatoes, rice and wood and cellulose-containing materials.

Morrison, Frank B. Feeds and Feeding, 21st edition. Ithaca, New York. The Morrison Publishing Co. 1951.

Dry matter percentages of various plant parts are as follows: sugar beet roots (16.4%), sugarbeet tops (17.8%), cassava roots (32.6%), napier grass (21.9%), potato tubers (21.2%), sugarcanes (23.2%), sugarcane tops and leaves (24.7%), sweet potato tubers (31.8%) and tomato fruit (5.7%).

Nelson, L.F. and W.C. Burrows. Putting the U.S. agricultural energy picture into focus. ASAE Paper No. 74-1040. 1974.

Major inputs of energy into agriculture are for on-and off-highway vehicles, the manufacture of chemicals and farm equipment and crop drying and irrigation. Ways for reducing energy inputs to agriculture and the resulting effects on production are discussed. More energy per unit area is used to produce corn than to produce any other major U.S. crop.

Parvin, D.W. and L.R. Nelson. A technique for evaluating the economic feasibility of irrigation research. J. of Soil and Water Conserv. 28(6):273-274. 1973.

A technique has been developed to estimate irrigation response from time-series non-irrigated data. The technique can help a researcher decide whether field research with a certain crop and region is warranted.

Protein from sugarcane waste. USDA Sci. Rev. 11(1):30. 1973.

The Division of Engineering Research at Louisiana State University has developed a process whereby bacteria is used to convert cellulose from waste sugarcane bagasse into a powder with a 50-60% crude protein content.

Szego, George C. and Clinton C. Kemp. Energy forests and fuel plantations. Chemtech. pp. 275-284. May 1973.

A case is made for growing organic matter for a raw material source in fuel production. Among the advantages of this type of fuel production are the perpetual renewability of the raw material source, lack of potential hazards and the ability of plants to store the sun's energy. The authors maintain that areas of similar size to craft pulp mills in the south could be managed for a generating station of a capacity comparable to many modern stations. Forest yields could probably be greater with a change in conventional management techniques. Estimates of fuel costs range from \$.93 - 1.80/GJ (\$.98 - 1.90/10^6Btu) depending upon the crop, rotation cycles, method of funding and other factors.

Whitaker, F.D. and H.G. Heinemann. Fertilizing corn during dry years. Univ. of Mo. Agric. Expt. Sta. Bull. 853. 1966.

Adequately fertilized corn was more efficient in using soil moisture than corn that was less adequately fertilized. For every 2.54 cm (1 in.) of soil moisture used by adequately fertilized, moderately fertilized, and

unfertilized corn, 314, 126 and 63 kg of grain/hm^2 (based on 5, 2 and 1 bu/acre and assuming 56 lb/bu) was produced, respectively.

Young, Harold E., Lars Strand and Russell Altenberger. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agric. Expt. Sta. Tech. Bull. 12. November 1964.

An equation was developed which shows the relationship between fresh weight and tree dimensions for various tree components and the complete tree. Dry weight percentage was determined from one tree of each species. The seven species studied in the Maine experiment were white birch, red spruce, balsam fir, aspen, hemlock, white pine and red maple.

SUMMARY SOURCES

Archer, Sellers G. and Clarence E. Bunch. The American Grass Book. Norman, Oklahoma. University of Oklahoma Press. 1953.

Information on many grasses is given including a description of the grass, location of growth, propagation methods, growing season and average yield.

Bibliography on alcohol production and use of agricultural crops as a source of motor fuels. ARS-USDA. Northern Regional Laboratory. Peoria, Ill.

Among the topics covered are alcohol-gasoline blends, the production, use and economics of alcohol, gas production from agricultural residues, the use of wheat in the war alcohol program and the production of alcohol from cereals.

Blaxter, Kenneth. Power and agricultural revolution. New Scientist 61(885): 400-403. 1973.

Information is presented on inputs and outputs in food production in Great Britain. Spartina townsendii, a vigorous C_4 plant with better than average response to solar radiation, has been discovered in Great Britain.

Clark, T.F., S.C. Uhr and I.A. Wolff. A search for new fiber crops. X. Effect of plant maturity and location of growth on kenaf composition and pulping characteristics. TAPPI 50(11):52A-56A. 1967.

Physical and chemical characteristics are presented for kenaf which was grown in Putnam County, Northern Florida and in Peoria County, Central Illinois and harvested at different levels of maturity. Production factors discussed include variety, soil type, fertilizer treatment, plant spacing and planting and harvesting dates.

Decker, Wayne L. Temperatures critical to agriculture. N.C. Regional Research Publ. No. 174. Mo. Agric. Expt. Sta. Bull. 864. 1967.

A summary of the distribution over the North Central Region of the United States of runs of days with critically high, critically low and favorable temperature conditions is presented.

Gonzalez, M. Rendimiento de plantaciones forestates en el tropico. (Yield of forest plantations in the tropics). An Cient. (La Molina) 8(1/2):109-121. 1970.

A bibliographic review of the production of tropical plantations is presented. Average yearly increases for various genera are Eucalyptus, 20-30 $m^3/hm^2 \cdot yr$ (17.6 - 26.4 t dry matter/$hm^2 \cdot yr$ assuming 55 lb/ft^3), Pinus, 15-20 $m^3/hm^2 \cdot yr$ (9.6 - 12.8 t dry matter/$hm^2 \cdot yr$ assuming 40 lb/ft^3) and Tectona (teak), 2 - 5 $m^3/hm^2 \cdot yr$ (1.2 - 2.9 t dry matter/$hm^2 \cdot yr$ assuming 36 lb/ft^3).

Kenaf leaf development and stem height index of crop yield in the United States. ARS-USDA Tech. Bull. No. 1477. February 1974.

Leaf development and stem height of the annual fiber plant kenaf (Hibiscus cannabinus L.) were used as measures of crop response to environment and as measures of leaf and stem yield. From the data collected at Glen Dale, Maryland, kenaf yields for various locations throughout the United States were predicted and tables, graphs and maps were prepared. The maximum oven-dry yield of kenaf stems at Glen Dale for the period from 1961-69 was 17.1 t/$hm^2 \cdot yr$ during 1962. The crop was planted April 16, the first frost was on October 24 and harvest date was November 28. The maximum oven-dry leaf yield was 3.5 t/$hm^2 \cdot yr$ in the early summer of 1968, however, when harvested just prior to frost, leaf yields were approximately 2.3 t/$hm^2 \cdot yr$. Predicted yields for various locations throughout the country range from 5 to over 45 t/$hm^2 \cdot yr$, the higher yields occurring in such areas as southern Florida and Texas. The yield predictions assume adequate fertilization, soil moisture and good cultural practices.

Kukachka, Francis B. Properties of imported tropical woods. USDA Forest Res. Paper FPL 125. 1970.

The properties of over 100 tropical woods are reported.

Lutz, J.F. Veneer species that grow in the United States. USDA Forest Service Res. Paper FPL 167. 1972.

The properties of 156 U.S. tree species are reported.

Oplinger, E.S. and J.H. Torrie. Soybean varieties for 1974. Fact Sheet A1977. Coop. Ext. Prog., University of Wisconsin. 1974.

There were 95,547 hm^2 of soybeans produced in Wisconsin in 1973. The maximum average yield for 1971-73 was 3.6 t/hm^2·yr (3.3 t dry weight/hm^2·yr assuming 8% moisture), with var. Corsoy in Janesville, Wisconsin. Corsoy is a late-maturing hybrid with a 21% oil content.

Parsons, James J. Spread of African pasture grasses to the American Tropics. J. of Range Management 25(1):12-17. 1972.

The histories and descriptions of the following six grasses are given: guinea grass (*Panicum maximum*), para grass (*Brachiaria mutica*, [*Panicum pupurascens*]), molasses grass (*Melinis minutiflora*), Jaragua grass (*Hyparrhenia clandestinum*), and pangola grass (*Digitaria decumbens*). Included are propagation methods, location of growth, and some yield data.

Pimentel, David, L.E. Hurd, A.C. Bellotti, M.J. Forster, I.N. Oka, O.D. Sholes and R.J. Whitman. Food production and the energy crisis. Science 182: 443-449. 1973.

A detailed analysis of energy inputs and outputs in corn production is presented followed by suggested alternatives for reducing energy inputs in agriculture.

Proceedings of the World Symposium on Applied Solar Energy. The Association for Applied Solar Energy. Phoenix, Arizona. November 1-5, 1955.

The potentials of algae as an energy converter are presented. In pilot plants, algae has produced up to 45 t of dry matter/hm^2·yr, while estimates of potential yields are as high as 86.5 to 123.0 t dry matter/hm^2·yr. Cost estimates are presented.

Schoenmann, J.A., R.D. Powell, J.L. Libby, E.K. Wade and L.K. Binning. Commercial onion production (dry bulb). Fact Sheet A2332. Coop. Ext. Prog., University of Wisconsin. 1974.

Approximately 648 hm^2 of onions are produced annually in Wisconsin. Dry bulb yields range from 22.4 to 56.0 t/hm^2·yr (2.5 - 6.2 t dry matter/hm^2·yr assuming 89% moisture). Production costs are realtively high.

Smith, J.H.G. and D.S. DeBell. Opportunities for short rotation culture and complete utilization of seven northwestern tree species. The Forestry Chronicle 49(1):31-34. 1973.

This article summarizes the data available on short rotation culture and complete tree utilization in the Pacific Northwest. Information in table form includes conversions between volume and weight, weight distribution of above ground components, dry weight yields as affected by spacing and fertilizer. The oven-dry weight of black cottonwood planted in a 61 x 61 cm spacing plan at a rotation length of two years is 11.65 $t/hm^2 \cdot yr$. New establishment methods are necessary for short rotation farming.

Steinbeck, Claus, Robert G. McAlpine and Jack T. May. Short rotation culture of sycamore: A status report. J. Forestry 70:210-213. 1972.

The concept of "short rotation hardwoods" or "silage sycamore" refers to the application of agricultural row crop techniques to forestry. Trees, planted at spacings as close as 30.5 x 121.9 cm are fertilized, cultivated and kept weed free. Coppicing is on rotations of less than ten years and harvesting is conducted with machines similar to corn silage harvesters. American sycamore (Plantanus occidentalis L.) seedlings grown in the Bottomland Piedmont of Georgia at a spacing of 30.5 x 121.9 cm and fertilized with 560 kg of 10-10-10/$hm^2 \cdot yr$ gave a fresh yield of 74.0 t/hm^2 (approximately 33.6 t dry weight/hm^2) when harvested after four years. Low cost stocking may be possible with horizontal planting of cuttings.

Thirring, Hans. Energy for Man. Bloomington. Indiana University Press. 1958.

One section of the book is devoted to fuels obtainable from vegetation. Wood, farm wastes, algae and alcohol from plants are all discussed. Under laboratory conditions, chlorella may give a dry matter yield of 168.1 $t/hm^2 \cdot yr$. The heat value of this dry matter is 20.9 - 29.3 MJ/kg.

Tinker, Jon. Waterweeds: flies in the irrigation ointment. New Scientist. pp. 747-749. March 21, 1974.

Five groups of waterweeds, usually thought of as pests because of their rapid spreading capabilities, could have possibilities as organic raw material for fuel production. Extremely effective control of the "weeds" would be necessary. Among the species covered are those which float freely on the surface without rooting - water hyacinth (Eichornia crassipes), duckweed (Lemna), water lettuce (Pistia stratiotes) and the South American water fern (Salvinia); those which are rooted, floating plants - lotus (Nelumbo nucifera) and water lily (Nymphae); those which are rooted but have submerged foliage - wild celery or tape grass (Valisneria), pondweed (Potamogeton) and Hydrilla verticilata; those which root along the edges of lakes and canals and have foliage which sticks up out of the water - reedmace or bulrush (Typha)and alligator weed (Alternanthera);

and finally, the algae, which bloom in warm nutrient-rich water - green Cladophora, blue-green Microcystis and the lime-encrusted stoneworts Chara and Nitella. In Kashmir, the water fern Salvinia can accumulate up to 3260 kg of biomass/hm^2 during the month of August when sunlight is intense. The article covers the waterweed problem in tropical Asia and Africa, however, some of the weeds grow in the United States.

Whitehead, D.C. The Role of Nitrogen in Grassland Productivity. Farnham Royal: Commonwealth Agricultural Bureaux. 1970. Book review by Roy Hughes in Experimental Agriculture 7(2):189. 1971.

One of three major parts of the book is devoted to yield responses of grass swards to fertilizer nitrogen.

Young, H.E. Challenge of complete tree utilization. Forest Products J. 18(4):83-86. 1968.

A review of the complete tree concept is presented. Intensive management of areas similar to agricultural crops and complete forest utilization are future possibilities. A study of five softwood species, three hardwood species, alder, willow and highbush blueberry was made. Trees of different size classifications were cut into components and weighed in the field.

APPENDIX B

PATHWAYS OF CARBON FIXATION

by R. Bruce Curry

Research has shown that there are two different carbon fixation pathways in higher plants. The C_3 pathway, or the "Calvin Cycle" is that in which a 3-carbon phosphoglyceric acid is the first product formed in carbon fixation. The other pathway, termed C_4, is that in which a 4-carbon compound oxaloacetic acid is the first product formed (Hatch and Slack, 1970). See Figures 1 and 2 of this appendix for a more detailed outline of the two pathways.

The difference between these two biochemical cycles has many important ramifications for higher plants, and particularly for those used economically. First of all, the efficiency of conversion of light and CO_2 to carbohydrate is higher in the C_4 plants. This means that for a given amount of solar energy a greater amount of carbohydrate is produced by the C_4 plant.

Among the other differences between C_3 and C_4 plants are the low CO_2 compensation point, the absence of photorespiration, higher optimum temperature and a difference in leaf anatomy of C_4 plants. These factors make C_4 plants more competitive and contribute to the increased efficiency mentioned above.

Some examples of C_4 plants of economic importance are maize, sugarcane and sorghum. The group also includes other warm season grasses, and some specially adapted desert plants.

To summarize, if one is looking for maximum production of simple carbohydrates, the plants in the C_4 group are the first place to look because of their highly efficient photosynthetic pathway.

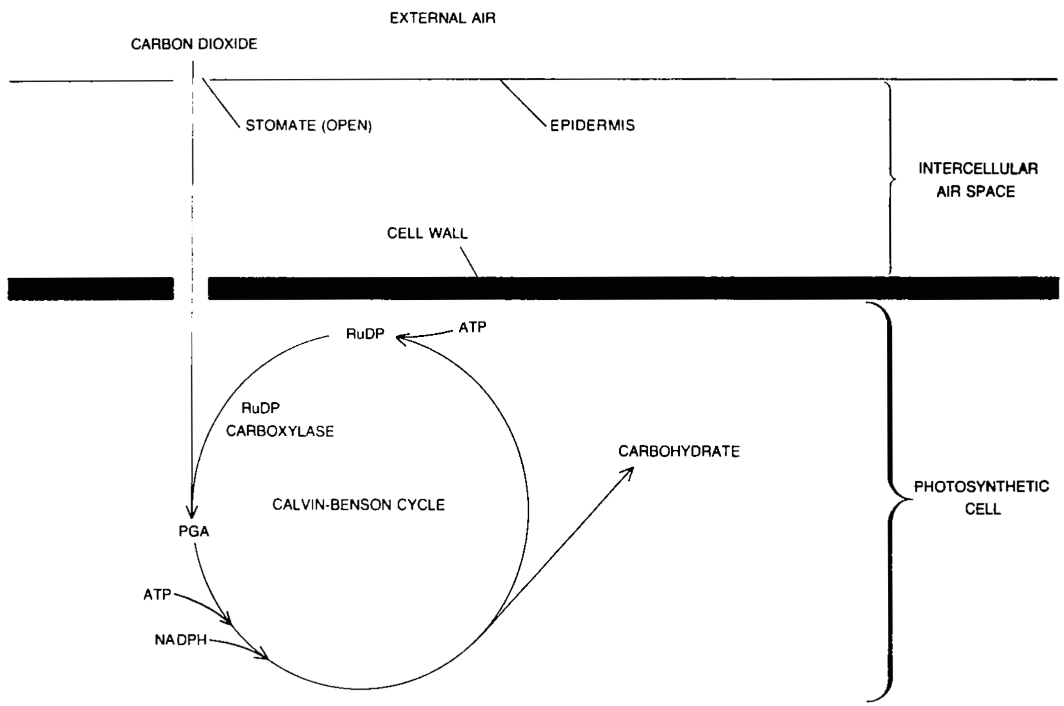

Fig. 1. Three-carbon photosynthetic pathway. (From Björkman and Berry, 1973).

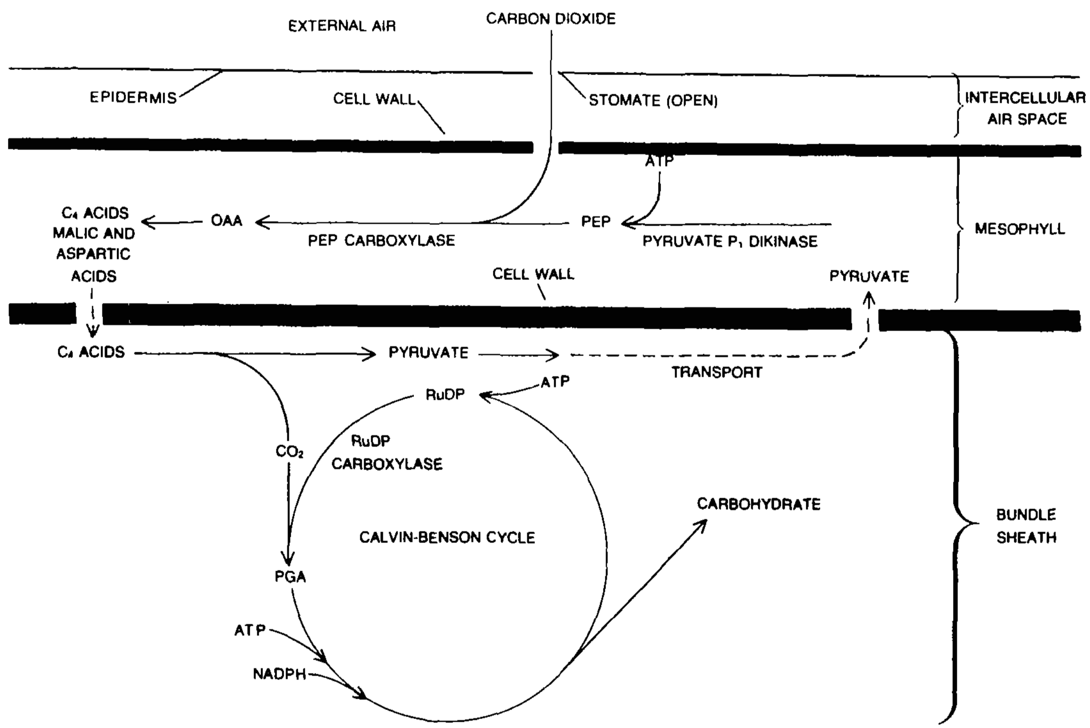

Fig. 2. Four-carbon photosynthetic pathway. (From Björkman and Berry, 1973).

APPENDIX C

POSSIBLE IMPROVEMENT OF PLANT SPECIES THROUGH GENETICS

by Rochelle D. Kline

A review by Einspahr (1972) indicates the possibilities for improving trees by such genetic techniques as "plus-tree" selection, hybridization, mutagenesis and polyploidy. The table below summarizes predicted genetic gains for height growth, diameter growth, volume growth and specific gravity for southern pines, western pines and Populus species. The predicted gains are based on moderate-intensity first generation selection, a progeny-tested seed-orchard and a review of research papers on the topic.

Summary of Genetic Gains[a]

Property	Predicted Genetic Gain, %
Height of growth	
Southern pines	6 - 12
Western pines	12
Populus species	10
Diameter of Growth	
Southern pines	10
Populus species	6 - 12
Volume Growth	
Southern pines:	
Individual trees	10 - 12
Per acre basis	20 - 50
Specific Gravity	
Southern pines	4 - 9
Populus species	2 - 6

[a] Table adapted from Einspahr, (1972).

APPENDIX D

EVALUATION OF THE OPTIMUM FERTILIZER RATES TO MAXIMIZE EXPECTED NET INCOME: DECISION IN FACE OF RISK[1]

by Harold M. Keener

The net income equation for a biomass production system can be written as:

$$I = Py - \sum_{i=1}^{4} c_i r_i y_{fi} - CF$$

where

I = net income, $\$/hm^2$

P = selling price of biomass, $/kg

y = yield of crop, $kg/hm^2 \cdot yr$ is assumed to vary from year to year depending on solar radiation, rainfall and temperature during growing season. The distribution of yields obtained over a period of years can be described with the probability density function f(y). This distribution is obtained when soil nutrients are at their maximum levels and not restricting crop yield.

r_i = ratio of fertilizer element i in the plant material produced, kg/kg.

c_i = cost of fertilizer element i, $/kg

i = 1, nitrogen

= 2, phosphorus, P_2O_5

= 3, potassium, K_2O

= 4, calcium, Ca

CF = total fixed cost of production (land, planting, tilling and harvesting), $\$/hm^2$

[1] Based on Keener and Mederski, 1974.

In developing the net income equation for a biomass production system, the cost of nutrients is dependent on the yield sought by fertilization. Actual crop yield determines the amounts of phosphorus, potash and calcium (assuming leaching and erosion losses for these elements are minimal) which need to be added to restore the soil to its maximum fertility level. Thus, for the farmer who fertilizes according to amounts removed by prior crops:

$$y_{f2} = y_{f3} = y_{f4} = y.$$

However, nitrogen losses from the soil depend not only on crop yields but on leaching and denitrification as well. Thus, replacement of nitrogen on the basis of that removed will not restore the soil to its maximum nitrogen fertility level. The expected income when fertilizing a crop with nitrogen level y_{f1} and phosphorus, potash and calcium at level y is:

$$E(I) = (P-b) \int_{0}^{y_{f1}} yf(y)dy + y_{f1} \int_{y_{f1}}^{\infty} f(y)dy - c_1 r_1 y_{f1} - CF$$

where $$b = \sum_{i=2}^{4} c_i r_i$$

This equation is based on the concept of most limiting factor. The first integral indicates the fractional number of years that yield can never exceed the level supported by climatic factors. The second integral indicates the number of years that yield cannot exceed the level supported by the nutrient nitrogen, regardless of climatic factors.

To find the optimum fertilization level, y_{f1}*, to maximize expected net income E(I), set

$$\frac{dE(I)}{dy_{f1}} = 0$$

and solve for y_{f1}. Solution of $\frac{dE(I)}{dy_{f1}} = 0$ gave

$$F(y_{f1}^*) = \frac{P - b - c_1 r_1}{P - b}$$

where
$$F(y_{f1}^*) = \int_0^{y_{f1}} f(y)dy$$

The expression for finding expected yield when a crop is fertilized at level y_{f1}^* is

$$\bar{y}^* = \int_0^{y_{f1}^*} yf(y)dy + y_{f1}^* \int_{y_{f1}^*}^{\infty} f(y)dy$$

The use of these equations is illustrated in the following example in which the optimum fertilization level for slash pine has been determined.

Data for Slash Pine Calculations.

		r_i kg/kg	c_i \$/kg	$r_i c_i$
1	Nitrogen (N)	.0038	.086	.000327
2	Phosphorus (P_2O_5)	.0009	.073	.0000657
3	Potash (K_2O)	.0016	.032	.0000512
4	Calcium (Ca)	.0016	.030	.0000480

$$b = 1.649 \times 10^{-4}$$

Let $P = \$.01/\text{kg}\ (\$10/\text{t})$

Then, $$F(y_{f1}^*) = \frac{.010 - .000165 - .000327}{.010 - .000165} = 0.967$$

For slash pine $y \simeq N(14.51, 1.84)$

Thus, $F(y_{f1}^*) = .967, \quad y_{f1}^* = 18.4$

Solution of equation for $\bar{y}^*$ gave

$$\bar{y}^* = 14.49.$$

APPENDIX E

METHOD OF CALCULATING CROP PRODUCTION COSTS

by Harold M. Keener and Rochelle D. Kline

Tables E-1 and E-2 give the costs and energy requirements of various inputs to crop production. All energy values were calculated on the basis of the energy requirements in fossil fuel to produce the material or energy. For example, 1 kwh of electricity is equivalent to 14.2 MJ of fossil fuel energy.

Tables E-1 and E-2 and the information below were used to calculate the costs and energy requirements of producing alfalfa, corn, kenaf, napier grass, slash pine and sycamore.

Interest on operating cost was 9% and was compounded over the length of the growing cycle. Operating costs included seed, labor, chemicals, fuel, fertilizer and other miscellaneous expenses (fertilizer spreader rental, small tools, soil tests).

Equipment costs were calculated as follows:

$$\text{Dollar costs} = \frac{0.25/\text{yr} \times \text{cost of equipment} \times \text{cycle time}}{162\ \text{hm}^2}$$

$$\text{Energy requirements} = \frac{\text{energy to manufacture equipment} \times \text{cycle time}}{1295\ \text{hm}^2/\text{yr}}$$

Land charge and the dollar return to management were each assumed to be $\$98.80/\text{hm}^2\cdot\text{yr}$, regardless of cycle time.

The energy requirements associated with seed production were based on the energy needed to grow and harvest the crop and not the energy content of the seed. The energy cost of cleaning and sorting seeds was not included.

TABLE E-1a. Cost of Field Machinery.

Description	Price $/machine	Weight kg
70 Hp tractor	13225	3727
Skidding, wheeled tractor	13225	3727
Moldboard plow 40 cm (4-16 in)	1550	552
Chisel plow, 2.1 m (7 ft)	750	580
Disc, 3.7 m (12 ft)	1625	1007
Springtooth, 3.7 m (12 ft)	475	254
Seed drill, 2.9 m (9.5 ft)	2350	786
Corn planter 76 cm (6-30 in)	4550	1395
Tree planter	2000	227
Sprayer, 3.0 m (10 ft)	850	454
Cultivator, 76 cm (6-30 in)	1525	750
Direct cut forage harvester	4850	1534
2-row forage harvester	5450	1582
Forage wagon	2850	1818
Chain saw	200	14
Fertilizer spreader	Rent	

TABLE E-1b. Energy Requirements of Using Field Machinery[a].

Description	Mfd Energy[b] MJ/machine	Fuel l/hm^2	Fuel Energy[c] MJ/hm^2	Labor man hr/hm^2	Labor Energy[d] MJ/hm^2
70 Hp tractor	592220	---------------------Based on Operation-----------------			
Skidding[e]					
Wheeled tractor	592220	1317.2	46759.9	129.40	173.40
Moldboard plow					
40 cm (4-16 in)	66960	25.3	896.4	1.19	1.59
Chisel plow					
2.1 m (7 ft)	60355	13.6	481.0	0.64	0.86
Disc, 3.7 m (12 ft)	122150	9.1	322.3	0.42	0.56
Springtooth					
3.7 m (12 ft)	30810	---------------------Used with disc---------------------			
Seed drill					
2.9 m (9.5 ft)	95340	3.0	106.1	0.57	0.76
Corn planter					
76 cm (6-30 in)	169215	6.2	219.0	0.38	0.51
Tree planter	27535	65.8	2334.1	10.40	13.94
Sprayer					
3.0 m (10 ft)	55070	2.5	90.2	0.23	0.31
Cultivator					
76 cm (6-30 in)	90975	8.0	284.7	0.38	0.51
Direct cut harvester					
Alfalfa	186075	(4.6)[f]	(163.9)[g]	1.42	1.90
Napier Grass	186075	(2.1)[f]	(75.5)[g]	1.42	1.90
Sycamore	186075	(1.5)[f]	(53.8)[g]	(0.08)[h]	(0.11)[i]
2-row forage harvester	191895	(1.5)[f]	(53.8)[g]	(0.08)[h]	(0.11)[i]
Forage wagon	220525	(5.3)[j]	(188.0)[k]	-----Same as harvester------	
Chain saw	1700	---------------------Included in skidding operation-------			
Fertilizer spreader		2.4	85.9	0.22	0.29

[a] From Weygandt, Inc. (1974), Hahn (1974), Biler and Johnson (1973), Shea (1968), and Frith and Promersberger (1973).

[b] Energy to produce steel = 79.5 MJ/kg.
Energy to produce tractors = 158.9 MJ/kg.
Energy to produce equipment other than tractors = 121.3 MJ/kg.

TABLE E-1b. Continued.

[c] Energy content of fuel = 35.5 MJ/1
[d] Labor requires 1.34 MJ/man-hr.
[e] Logging based on pulpwood operations at ~ 299 t/hm[2] on a dry matter basis. Does not include loading or trucking.
[f] 1/t
[g] MJ/t
[h] Man-hr/t
[i] MJ/t
[j] 1/hr
[k] MJ/hr

TABLE E-2. **Dollar Costs and Energy Requirements of Miscellaneous Inputs[a].**

Description	Dollar Cost	Energy In Production
Fuel	\$0.106/1	35.5 MJ/1
Labor	3.50/hr	1.34 MJ/man-h
Nitrogen	0.42/kg	64.40 MJ/kg
P_2O_5	0.35/kg	11.96 MJ/kg
K_2O	0.15/kg	11.96 MJ/kg
Lime[b]	6.60/tonne	0.46 MJ/kg
Herbicides	5.50/kg	101.20 MJ/kg
Insecticides	5.50/kg	101.20 MJ/kg
Electricity[c]	.0028/MJ	241.71 MJ/hm^2.y

[a] From U.S. Steel Agricultural Chemicals (1974), Pimentel, et al. (1974), Steinhart and Steinhart, (1974).
[b] Includes a 40-mile transportation energy requirement of 0.18 MJ/kg lime.
[c] Assuming an electricity requirement of 17 kwh/hm^2·yr to operate farm shop, lights, etc., and a requirement of 14.22 MJ of fossil fuel to produce 1 kwh of electricity.

COSTS AND ENERGY REQUIREMENTS - ALFALFA (OHIO)

Item		Dollar $/hm^2 \cdot$cycle	Energy MJ/$hm^2 \cdot$cycle
Return on Investment		296.40	------
Land		296.40	------
Equipment	$43,850	203.06	4934.2
Seed	13.4 kg/hm^2	68.12	426.6
Labor	27.24 hr/hm^2	100.60	36.0
Chemicals	13.4 kg/hm^2	77.44	1363.3
Fuel	297.3 l/hm^2 + 737.0 MJ/hm^2	33.58	11291.2
Fertilizer		391.89	22029.4
Misc. Expenses		29.69	------
	Total cost per hm^2	1497.18	40080.7
	Cost per tonne	41.09	1100.2

Cycle time = 3 years

Yield = 36.43 t/hm^2

Equipment = 2 tractors, plow, discs, springtooth, drill, sprayer, harvester, 2 forage wagons

Fertilizer used = 0 kg N, 446 kg P_2O_5, 1233 kg K_2O and 4.13 t lime/hm^2

Operations = Fertilize (3)[a], plow, till (2), plant, spray (6), harvest (8), transport to collection site (8).

[a] Numbers in parentheses refer to the number of operations performed over the cycle time.

COSTS AND ENERGY REQUIREMENTS - CORN (OHIO)

Item		Dollar $\$/hm^2 \cdot cycle$	Energy $MJ/hm^2 \cdot cycle$
Return on Investment		98.80	------
Land		98.80	------
Equipment	\$45,170	69.73	1765.2
Seed	16.8 kg/hm^2	24.23	123.8
Labor	5.78 hrs	22.06	7.75
Chemicals	4.5 kg/hm^2	26.92	454.6
Fuel	79.7 l/hm^2 + 245.7 MJ/hm^2	9.96	3075.2
Fertilizer		191.57	19419.1
Misc. Expenses		18.85	------
	Total cost per hm^2	560.92	24845.7
	Cost per tonne	29.06	1287.3

Cycle time = 1 year

Yield = 19.3 t/hm^2

Equipment = 2 tractors, plow, discs, springtooth, planter, sprayer, forage harvester, 2 forage wagons.

Fertilizer used = 235 kg N, 110 kg P_2O_5, 193 kg K_2O and 1.32 t lime/hm^2

Operation Sequence = fertilize, plow, till (2), plant, spray, harvest, transport to collection site.

COSTS AND ENERGY REQUIREMENTS - KENAF (FLORIDA)

Item		Dollar $\$/hm^2 \cdot cycle$	Energy $MJ/hm^2 \cdot cycle$
Return on Investment		98.80	------
Land		98.80	------
Equipment	\$45,170	69.73	1765.2
Seed	9.0 kg/hm^2	21.54	227.1
Labor	5.82 hrs/hm^2	22.24	7.8
Chemicals	4.5 kg/hm^2	26.92	454.6
Fuel	80.1 l/hm^2 + 245.7 MJ/hm^2	10.00	3089.0
Fertilizer		174.23	17244.9
Misc. Expenses		18.85	------
	Total cost per hm^2	541.11	22788.6
	Cost per tonne	27.75	1168.6

Cycle time = 1 year

Yield = 19.5 t/hm^2

Equipment = 2 tractors, plow, discs, springtooth, planter, sprayer, forage harvester, 2 forage wagons.

Fertilizer used = 200 kg N, 99 kg P_2O_5, 209 kg K_2O, and 1.23 t $lime/hm^2$

Operation Sequence = fertilize, plow, till, plant, spray, harvest, transport to collection site.

COSTS AND ENERGY REQUIREMENTS - NAPIER GRASS (PUERTO RICO)

Item		Dollar $/hm^2 \cdot$cycle	Energy MJ/hm$^2 \cdot$cycle
Return on Investment		296.40	------
Land		296.40	------
Equipment	$43,850	203.06	4933.8
Seed		56.76	1791.9
Labor		119.72	43.5
Chemicals		25.81	454.6
Fuel		51.23	16358.3
Fertilizer		1666.42	155607.7
Misc. Expenses		45.15	------
	Total cost per hm^2	2760.95	179189.8
	Cost per tonne	18.22	1182.8

Cycle time = 3 years

Yield = 151.5 t/hm^2

Equipment = 2 tractors, plow, discs, springtooth, drill, sprayer, harvester, 2 wagons

Fertilizer used = 1674 kg N, 1402 kg P_2O_5, 2382 kg K_2O, and 4.65 t lime/hm^2

Operations = Fertilize (6), plow, till (2), plant, spray, harvest (10), transport to collection site (10).

COSTS AND ENERGY REQUIREMENTS - SLASH PINE (LOUISIANA)

Item		Dollars $/hm²·cycle	Energy MJ/hm²cycle
Return on Investment		1976.00	------
Land		1976.00	------
Equipment	$32,550	1005.80	22554.7
Seed	3400 trees/hm^2	380.80	890.7
Labor	142.8 hrs/hm^2	705.75	191.1
Chemicals	4.5 kg/hm^2	138.60	455.4
Fuel	1428.3 l/hm^2 + 245.7 MJ/hm^2	240.59	51011.2
Fertilizer		2783.21	102697.0
Misc. Expenses		97.10	------
	Total cost per hm^2	9303.85	177800.1
	Cost per tonne	32.06	612.7

Cycle time = 20 years

Yield = 290.2 t/hm^2

Equipment = 1 tractor, 1 rubber tired skidder, chisel plow, disc, springtooth, planter, sprayer, 2 chain saws

Fertilizer used = 1400 kg N, 261 kg P_2O_5, 464 kg K_2O, and 8.4 t lime/hm^2

Operations = Burn, fertilize (5), chisel plow, till, plant, spray, harvest and skid to collection site.

COSTS AND ENERGY REQUIREMENTS - SYCAMORE (GEORGIA)

Item		Dollar $\$/hm^2 \cdot cycle$	Energy $MJ/hm^2 \cdot cycle$
Return on Investment		988.00	------
Land		988.00	------
Equipment	$42,700	659.17	21479.9
Seed	6900 trees/hm^2	261.15	696.3
Labor	39.7 hr/hm^2	194.50	53.2
Chemicals	4.5 kg/hm^2	46.63	454.6
Fuel	427.2 l/hm^2 + 245.7 MJ/hm^2	60.94	15412.0
Fertilizer		1779.07	105441.6
Misc. Expenses		32.65	------
	Total cost per hm^2	5010.11	143537.6
	Cost per tonne	31.00	888.8

Cycle time = 10 years

Yield = 161.5 t/hm^2

Equipment = 2 tractors, chisel plow, discs, springtooth, planter, sprayer, chopper, 2 wagons

Fertilizer used = 1400 kg N, 448 kg P_2O_5, 762 kg K_2O, and 6.0 t lime/hm^2

Operations = fertilize (5), chisel plow, till (2), plant, spray, harvest (5), transport to collection site (5).

APPENDIX F

CONSUMPTION OF ENERGY IN MATERIALS PRODUCTION AND HEATS OF COMBUSTION OF FUELS

by Rochelle D. Kline and Harold M. Keener

ENERGY INPUTS IN PRODUCTION OF MATERIALS

Material	Given Energy Input	Note	Energy Input (Btu/lb)	MJ/kg	Reference[a]
Plastics (not specified)	1.25×10^6 kcal/ton		2480	5.77	5
Chlorine	5450 Btu/lb	(1)	5450	12.69	8
	9550 Btu/lb	(2)	9550	22.23	3
Vinyl chloride	1260 Btu/lb	(3)	1260	2.93	8
	3620 Btu/lb	(2)	3620	8.43	3
Polystyrene	1240 Btu/lb	(4)	1240	2.89	8
	1980 Btu/lb	(2)	1980	4.61	3
Polyvinyl chloride	2500 Btu/lb	(5)	2500	5.82	8
	1260 Btu/lb	(2)	1260	2.93	3
Ethylene (ex-ethane)	8650 Btu/lb	(2)	8650	20.14	3
Ethylene	12,700 Btu/lb	(6)	12700	29.57	2
	8720 Btu/lb	(7)	8720	20.30	2
Polyethylene	2470 Btu/lb	(8)	2470	5.75	2
Polyethylene (High density)	1850 Btu/lb	(2)	1850	4.31	3
Polyethylene (Low density)	3520 Btu/lb	(2)	3520	8.19	3
Polypropylene	4120 Btu/lb	(2)	4120	9.59	3
Nitrogen	8400 kcal/lb	(9)	33331	77.60	9
	11.48×10^6 kcal/lb		45552	106.05	1
	2.95×10^6 cal/lb	(11)	11705	27.25	1
	9000 kcal/lb		35712	83.14	10
Phosphorus	1520 kcal/lb	(9)	6031	14.04	9
	3.83×10^6 cal/lb	(10)	15197	35.38	1
	3.67×10^6 cal/lb	(11)	14562	33.90	1
	1450 kcal/lb	(12)	5753	13.39	10
Phosphate fertilizer	10.4×10^6 Btu/ton	(12)	5200	12.11	7
Potassium	1050 kcal/lb	(9)	4166	9.70	9
	0.87×10^6 cal/lb	(10)	3452	8.04	1
	0.50×10^6 cal/lb	(11)	1984	4.62	1
	1000 kcal/lb		3968	9.24	10

[a] A separate reference list is included with this Appendix.

Energy Inputs in Production of Materials - continued.

Material	Given Energy Input	Note	Energy Input (Btu/lb)	MJ/kg	Reference[a]
Ammonia	$2.7x10^7$ kcal/ton		53568	124.71	5
	$37.2\text{-}41.5x10^6$ Btu/ton	(13)	18600	43.30	7
Ammonia compounds	$2.2x10^6$ kcal/ton		4364	10.16	5
Sodium Carbonate	$4.0x10^6$ kcal/ton		7936	18.48	5
Sulfuric acid and sulfur	$3.0x10^6$ kcal/ton		5952	13.86	5
Other inorganic chemicals (not specified)	$2.2x10^6$ kcal/ton		4364	10.16	5
Insecticides	11000 kcal/lb	(9)	43648	101.61	9
Herbicides	11000 kcal/lb	(9)	43648	101.61	9
Paper	$5.5x10^6$ kcal/ton		10912	25.40	5
Copper and Brass	$1.7x10^6$ kcal/ton	(14)	3372	7.85	5
Aluminum	$6.0x10^7$ kcal/ton	(15)	119040	277.13	5
Steel	$1.7x10^7$ kcal/ton	(16)	33728	78.52	5
	$1.9x10^4$ kcal/kg	(16)	34206	79.63	5
	25 gigajoules/ton liquid steel	(17)	11000	25.61	13
Cement	$1.2x10^6$ Btu/barrel	(18)	3630	8.45	4
	750,000 Btu/barrel	(19)	2270	5.28	4
	550,000 Btu/barrel	(20)	1660	3.86	4
Irrigation	$27.5x10^6$ Btu/acre receiving 5 acre-ft	(21)	2.025	0.005	6
	corn receiving 1 acre-ft/acre corn	(22)	1.337	0.003	9
Hybrid corn seed	1276 kcal/lb	(23)	5063	11.79	14
Wood	2909372 Btu/1000bf	(24)	1700	3.96	15
Rubber	---		---		--
Electricity (agricultural use)	310000 kcal fossil fuel/acre	(25)	($1.23x10^6$/acre)	3208.23 MJ/hm^2	9

FUELS - HEAT OF COMBUSTION (26)

Material	Heat of Combustion	Note	Heat of Combustion (Btu/lb)	MJ/kg	Reference
Crude oil	19502 Btu/lb	(27)	19502	45.40	12
Gasoline	36225 kcal/gal		23365	54.39	9
	9571 kcal/liter		23365	54.39	9
	125000 Btu/gal		20318	47.30	
	30.9 K joules/cm^3	(28)	21100	49.12	11
	44.3 K joules/g	(28)	21100	49.12	11
	20750 Btu/lb		20750	48.31	12
Oil and gasoline	$1.5x10^6$ kcal/barrel		23197	54.00	5
	$9.5x10^3$ kcal/liter		23197	54.00	5
Gas oil	19200 Btu/lb		19200	44.70	12
Coal	$6.6x10^6$ kcal/ton		13094	30.48	5
Coal coke	$26x10^6$ Btu/ton		13000	30.26	12
Petroleum coke	$30.12x10^6$ Btu/ton		15060	35.06	12

Material	Heat of Combustion	Note	Heat of Combustion (Btu/cu ft)	MJ/kg	Reference
Natural gas	260 kcal/cu ft		1032	0.04	5
	9200 kcal/m^3		1032	0.04	5
	1034 Btu/cu ft	(29)	1034	0.04	
	1050 Btu/cu ft		1050	0.04	12

NOTES

1. Start with crystalline salt, produce liquid chlorine and 50% caustic soda.
2. Estimates on battery limit basis. Don't include overhead requirements. Offsite requirements small.
3. Liquified. Blaw-Knox monomer process, no account for heat value of by-products.
4. Suspension technique. Pelletized.
5. Suspension technique. Intermediate molecular weight homopolymer.
6. Energy related to the cost feed stock and basic fuel (naptha). No account for by-products.
7. Considers ethylene from naptha, plus the main co-product, propylene.
8. Starting with ethylene.
9. Includes production and processing.
10. Computed assuming 17.4 million cal/dollar and N at $.66/lb., P at $.22/lb., K at $.05/lb.
11. Estimates of energy requirements for production prior to blending includes shipping costs to bulk plant in corn belt.
12. 85% of energy requirement is for sulfuric acid needed in phosphate manufacture.
13. Assuming 36-40 thousand cu ft natural gas required/ton ammonia (1034 Btu/cu ft natural gas).
14. Alloys, millings, castings and forgings.
15. Includes castings and forgings.
16. Includes fabricated and castings.
17. Production of liquid steel in Great Britain.
18. Average energy use in U.S. cement kilns.
19. Most efficient cement kilns in U.S.
20. European cement kilns. Represents efficiency of 55%.
21. 5-acre ft lifted 250 ft requires 1712 hp-hr. Assuming 60% pump efficiency and diesel engine delivering 13 hp-hr/gal. Total fuel requirement of 220 gal.
22. Energy requirement for 1 acre - ft water/acre corn·season.
23. Heat of combustion of 1 lb corn seed is 1800 kcal. In 1970 the ratio of kcal return/kcal input in corn production was 2.82 (Ref. 11). An estimate of the energy effort in producing hybrid corn seed was determined in the following way:

$$\left(\frac{1800 \text{ kcal}}{2.82 \text{ kcal/kcal}} \times 2\right) = 1276 \text{ kcal/lb}$$

24. Includes lumbering, milling, drying and transporting.
25. 1970.
26. The energy cost of producing the following fuels was not available.
27. Oklahoma.
28. Heat of combustion (low) to CO_2 and H_2O (gas).
29. Dry.

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APPENDIX G

DEFINITION OF SYMBOLS

Definition	Symbol
boardfoot	bf
British thermal unit	Btu
bushel	bu
calorie	cal
Celsius (temperature)	°C
centimeter	cm
cubic foot	cu ft
decimeter	dm
Fahrenheit (temperature)	°F
foot	ft
gallon	gal
gigajoule	GJ
gram	gm
hectometer	hm
horsepower	Hp
hour	hr
inch	in
joule	J
kilocalorie	kcal
kilogram	kg
kilometer	km
kilowatt hour	kwh
leaf area index	LAI
liter	1
mean	$\bar{x}$
megajoule	MJ
megameter	Mm
meter	m
milligram	mg
millimeter	mm
pound	lb
specific gravity	sp gr
standard deviation	S
ton	short ton (2000 lb)
tonne	metric tonne (t)
watts per meter squared	wm^{-2}
wet basis	w.b.
year	yr

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