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Energy Technology Impacts on Agriculture with a Bibliography of Models for Impact Assessment on Crop Ecosystems

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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1278

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ENERGY TECHNOLOGY IMPACTS ON AGRICULTURE WITH A BIBLIOGRAPHY OF MODELS FOR IMPACT ASSESSMENT ON CROP ECOSYSTEMS

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ABSTRACT

RUPP, E. M., R. J. LUXMOORE, and D. C. PARZYCK. 1979. Energy technology impacts on agriculture with a bibliography of models for impact assessment on crop ecosystems. ORNL/TM-6694. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 98 pp.

Issue: Impact of energy technologies on agricultural crops.

Problem: Severe and chronic effects, beneficial effects, possible unknown effects of energy technologies on agricultural ecosystems.

Purpose: Evaluation of current and projected energy technology impacts on agricultural crops with commentary on a bibliography of computer models for assessment of impacts on crop ecosystems.

This report undertakes to evaluate the possible impacts of energy technologies on agriculture and to identify some of the available simulation models that can be used for predictive purposes. An overview of energy technologies and impacts on the environment is presented to provide a framework for the commentary on the models. Coal combustion is shown to have major impacts on the environment and these will continue into the next century according to current Department of Energy projections. Air pollution effects will thus remain as the major impacts on crop ecosystems.

Two hundred reports were evaluated, representing a wide range of models increasing in complexity from mathematical functions (fitted to data) through parametric models (which represent phenomena without describing the mechanisms) to mechanistic models (based on physical, chemical, and physiological principles). Many models were viewed as suitable for adaptation to technology assessment through the incorporation of representative dose-response relationships. It is clear that in many cases available models cannot be taken and directly applied in technology assessment. This fact identifies the need for experienced input from personnel familiar with both modeling and

dose-response relationships to extend the application of models to technology assessment. Very few models of air pollutant-crop interactions were identified even though there is a considerable data base of pollutant effects on crops. In view of the continuing dependence on coal combustion for energy needs, the development and application of air pollution-crop models should be encouraged.

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INTRODUCTION

The environmental impacts of energy technology are likely to increase in the next 30 to 40 years with the expansion of energy production by traditional methods (coal combustion, nuclear fission) and alternative sources (geothermal, solar, wind). Some impacts are clearly detrimental and must be reduced in accordance with the clean air and water legislation, whereas other impacts may be chronic (heavy metal deposition) or even beneficial (waste heat utilization) to agricultural crops.

The diverse range of impacts from energy technology development requires careful evaluation for both detrimental and beneficial effects over long and short terms. Computer modeling is one tool that can aid in this important assessment by allowing the evaluation of complex biological and environmental interactions.

This paper is concerned with a bibliography of models of agricultural systems with commentary on their suitability for the environmental assessment of energy technologies, especially those impacts related to the anticipated intensive use of coal in future scenarios. We also present basic information on expected pollutant concentrations and relationships between pollutant concentration and biological responses. Representation of phenomena by simulation modeling is still a developing technique, and although conceptually it can provide the kinds of insights needed for assessment, at the present stage of development, deficiencies in the modeling capabilities and data sources may limit meaningful application.

ENERGY TECHNOLOGY DEVELOPMENT

In order to put the question of energy technology impacts on agriculture into proper perspective, it is necessary to examine projections of energy development and use. To perform a meaningful analysis, these projections must include a description of energy consumption by fuel type for each region of the country. The relative

importance of associated effluent releases can then be examined in relation to the agricultural land use within the region.

Estimates of energy consumption by fuel type were taken from the Annual Report to Congress prepared by the Energy Information Administration (1978). This report addressed projections of energy supply and demand for the years 1975, 1985, and 1990 by fuel type. Table 1, based upon information taken from the report for their mid-supply and mid-demand projection, shows a 34% increase in energy consumption between the years 1975 and 1985 and a 15% increase in consumption between 1985 and 1990. During the latter 15-year interval, petroleum continues to provide just under 50% of the total energy consumed.

The role of natural gas decreases during this period from a 28% share in 1975 to an 18% share in 1990. Coal receives increasing emphasis as a fuel alternative in that it is projected to contribute 23% of the total energy consumed in 1990, an increase of 5% over the figure for 1975. Similarly, nuclear energy undergoes a 7% increase in its contribution to the total energy consumed during the period from 1975 to 1990. Hydroelectric power contributes a constant 5% to the total energy consumed for the period of 1975-1990.

Most of the aforementioned technologies produce effluents which can impact agricultural productivity. Table 2 lists the pollutants specific to the energy technologies presented in Table 1 in approximately decreasing order according to the magnitude of the effluent release. Coal combustion, petroleum use (primarily gasoline), and natural gas use produce significant amounts of sulfur oxides, nitrogen oxides, particulates, carbon monoxide, carbon dioxide, hydrocarbons, aldehydes, and trace metals. Hydroelectric energy is free of this type of effluent release and nuclear power is associated with low levels of radioactive release that have minor impact on agricultural crops.

Table 1. Historical and projected estimates of energy consumption by fuel type from Energy Information Administration (1978)

	Quadrillion (10^{15}) Btu[a]		
	1975	1985	1990
Coal	12.8	21.2	25.4
Petroleum[b]	32.8	43.9	48.5
Natural gas	20.0	19.1	19.3
Hydro-electric	3.2	4.2	5.0
Nuclear	1.8	6.2	10.3
Total	70.6	94.6	108.5

[a]Projection Series C: mid-supply and mid-demand.

[b]Primarily gasoline, but also distillate and residual oil, liquid gas, jet fuel, and other petroleum products.

Table 2. Atmospheric effluents associated with principle energy technology alternates (from USDOE 1977, USEPA 1973, 1974b, 1975)

COAL COMBUSTION	NATURAL GAS USE
SO_2	NO_x
NO_x	CO
Particulates	CO_2
CO	Particulates
CO_2	Hydrocarbons
Hydrocarbons	SO_2
Aldehydes	
Trace elements[a]	HYDROELECTRIC USE
	None
PETROLEUM USE[b]	
CO	NUCLEAR ENERGY USE
CO_2	Radionuclides[c]
Hydrocarbons	
NO_x	
SO_2	
Particulates	

[a]Including nickel, chromium, lead, zinc, mercury, cadmium, and arsenic.

[b]Gasoline accounts for almost 75% of energy use in this sector.

[c]Including Xe-133, fission products, Kr-85, H-3, and I-131.

In addition to the technologies cited in Table 2 there are a number of new technologies which are expected to substitute for traditional fossil fuel technologies. However, with an upper bound projection from the Energy Information Administration (1978), these technologies as a group would substitute for less than 2% of the total demand in 1985 and just over 3% in 1990 (Table 3). The new technologies would therefore not have a significant impact in the near term. The magnitude of the potential impact of the emerging technologies upon agricultural crops must also be viewed from the standpoint of the effluent releases associated with the various technologies (Table 4). Only the synthetic fuel and geothermal technologies produce effluents with a significant potential impact on agricultural crops. The effluents produced by the synthetic fuel technologies are in many cases the same as those produced by coal combustion and so these technologies will not be addressed separately. Geothermal energy will play a relatively small role in the total energy picture for the near term, and present thinking is that this technology will be primarily developed in California, Idaho, and Oregon (Energy Information Administration 1978).

Just as it is very important to characterize the projections of energy technology mix and the effluents associated with the various technologies, it is equally important to determine the regional distribution of fuel use. Table 5 lists the various states which comprise the ten Department of Energy regions. The projected levels of energy generation by fuel type for the various regions of the country (Table 6) reveal that the greatest levels of coal use are projected for Department of Energy Regions III, IV, and V. The greatest levels of fuel oil use are projected for Regions I, II, IV, and IX. Region VI is by far the greatest user of natural gas, and Regions IV and V lead in the use of nuclear fuel for electricity production. Hydroelectric activity is concentrated in Region X.

Table 3. Projections of energy supplied by new and emerging technology alternatives (from Energy Information Administration 1978)

	Quadrillion (10^{15}) Btu[a]	
	1985	1990
Synthetic fuels	0.40	1.35
Geothermal energy	0.60	1.30
Solar energy	0.15	0.29
Wind energy	0.09	0.66

[a]Projections based on upper bound case assuming major government intervention.

Table 4. Atmospheric effluents associated with new and emerging technology alternatives (from U.S. Department of Energy, 1977)

SYNETHEIC FUELS	GEOTHERMAL
Oil shale	CO_2
SO_x	Ammonia
Hydrocarbons	Methane
NO_x	Hydrogen
CO	Hydrogen sulfide
CO_2	Nitrogen
Particulates	Argon
Aldehydes	
	SOLAR
HI/LO BTU GAS	Negligible
SO_x	
NO_x	WIND ENERGY
Particulates	None
CO	
CO_2	
Hydrocarbons	
Aldehydes	
LIQUEFACTION	
NO_x	
SO_x	
Particulates	
Hydrocarbons	

Table 5. Department of Energy regions (from Energy Information Administration 1978)

Region I, New England	Region VI, Southwest
Connecticut	Arkansas
Maine	Louisiana
Massachusetts	New Mexico
New Hampshire	Oklahoma
Rhode Island	Texas
Vermont	
Region II, New York/New Jersey	Region VII, Central
New Jersey	Iowa
New York	Kansas
	Missouri
	Nebraska
Region III, Mid Atlantic	Region VIII, North Central
Delaware	Colorado
District of Columbia	Montana
Maryland	North Dakota
Pennsylvania	South Dakota
Virginia	Utah
West Virginia	Wyoming
Region IV, South Atlantic	Region IX, West
Alabama	Arizona
Florida	California
Georgia	Hawaii
Kentucky	Nevada
Mississippi	
North Carolina	
South Carolina	
Tennessee	
Region V, Midwest	Region X, Northwest
Illinois	Alaska
Indiana	Idaho
Michigan	Oregon
Minnesota	Washington
Ohio	
Wisconsin	

Table 6. Generation of electricity by Department of Energy region (from Energy Information Administration 1978)

	Quantity (10^9 kWh)		
	1976	1985	1990
Region I, New England			
Coal	2.0	22.6	21.4
Fuel oil	43.0	54.7	23.9
Gas	0.3	0.0	0.0
Nuclear	25.2	23.9	57.3
Hydro	5.2	4.4	4.9
Region II, New York/New Jersey			
Coal	20.2	77.8	75.9
Fuel oil	64.6	59.1	47.0
Gas	1.4	0.1	0.1
Nuclear	19.5	52.4	98.0
Hydro	28.3	36.3	34.0
Region III, Mid Atlantic			
Coal	182.1	197.8	245.1
Fuel oil	39.6	15.9	15.1
Gas	0.3	2.7	4.2
Nuclear	30.5	86.0	93.5
Hydro	3.8	2.5	2.9
Region IV, South Atlantic			
Coal	260.5	440.5	587.5
Fuel oil	64.6	102.2	82.2
Gas	15.1	3.3	0.0
Nuclear	37.4	154.9	267.9
Hydro	35.7	41.2	40.5
Region V, Midwest			
Coal	316.3	425.1	461.0
Fuel oil	17.3	25.5	33.1
Gas	8.0	2.9	1.8
Nuclear	57.0	131.7	200.1
Hydro	3.4	3.7	4.1
Region VI, Southwest			
Coal	28.6	155.0	214.5
Fuel oil	15.6	10.3	12.1
Gas	213.9	161.8	125.3
Nuclear	3.9	42.4	77.6
Hydro	4.7	9.6	9.2

Table 6 (Continued)

	Quantity (10^9 kWh)		
	1976	1985	1990
Region VII, Central			
Coal	60.3	118.0	126.8
Fuel Oil	4.7	3.8	4.7
Gas	16.0	4.8	7.1
Nuclear	8.3	18.0	33.9
Hydro	2.7	2.7	2.8
Region VIII, North Central			
Coal	40.0	80.9	91.9
Fuel Oil	6.5	1.3	1.5
Gas	3.7	0.3	0.3
Nuclear	0.0	1.9	1.9
Hydro	26.1	27.5	28.9
Region IX, West			
Coal	22.8	28.4	28.0
Fuel Oil	69.2	61.2	59.2
Gas	34.1	27.7	29.2
Nuclear	4.8	35.4	61.1
Hydro	32.3	58.0	58.7
Region X, Northwest			
Coal	6.4	6.1	7.3
Fuel Oil	0.4	0.3	0.7
Gas	1.5	0.0	0.0
Nuclear	0.0	19.1	43.6
Hydro	140.4	176.4	184.6

While the impacts of effluent release are dependent upon such factors as topography, climate, weather, and the presence of other pollutant sources, it is possible to use information on fuel use and effluent type to characterize the relative severity of impact on agricultural crops for various regions of the country. Figure 1 shows the distribution of cropland among those counties which comprise the 48 contiguous states. The information presented in Fig. 1 was taken from the 1967 National Inventory of Soil and Water Conservation Needs (U.S. Department of Agriculture 1967). The heaviest concentration of cropland occurs in Department of Energy Regions VIII, V, VII, and VI with significantly lesser amounts in each of the remaining six regions. Of these four regions, three (the North Central, Midwest, and Central) will rely on coal for the majority of energy production through the year 1990, according to the projections presented in Table 6. The one remaining region (the Southwest) has developed a basic reliance on natural gas which will continue through the 1990 timeframe. It is anticipated that coal use will begin to surpass use of natural gas in the period beyond 1985, however. It can be stated, therefore, that crops grown in these four regions will be exposed to significant levels of effluents released by coal combustion facilities that have been shown to have an adverse impact on agriculture.

AGRICULTURAL EFFECTS

Nearly 60% of the land in the United States is being used to produce crops (20%) and livestock (40%) (Frey et al. 1968), and most of this land has received some impact from energy technology, considering the global increase in atmospheric CO_2 (Baes et al. 1977) and the regional increases in atmospheric SO_2 (USEPA 1974a). Considerable empirical data are available on certain aspects of energy technology pollutant effects on vegetation. There are four basic aspects to the evaluation of pollutant effects.

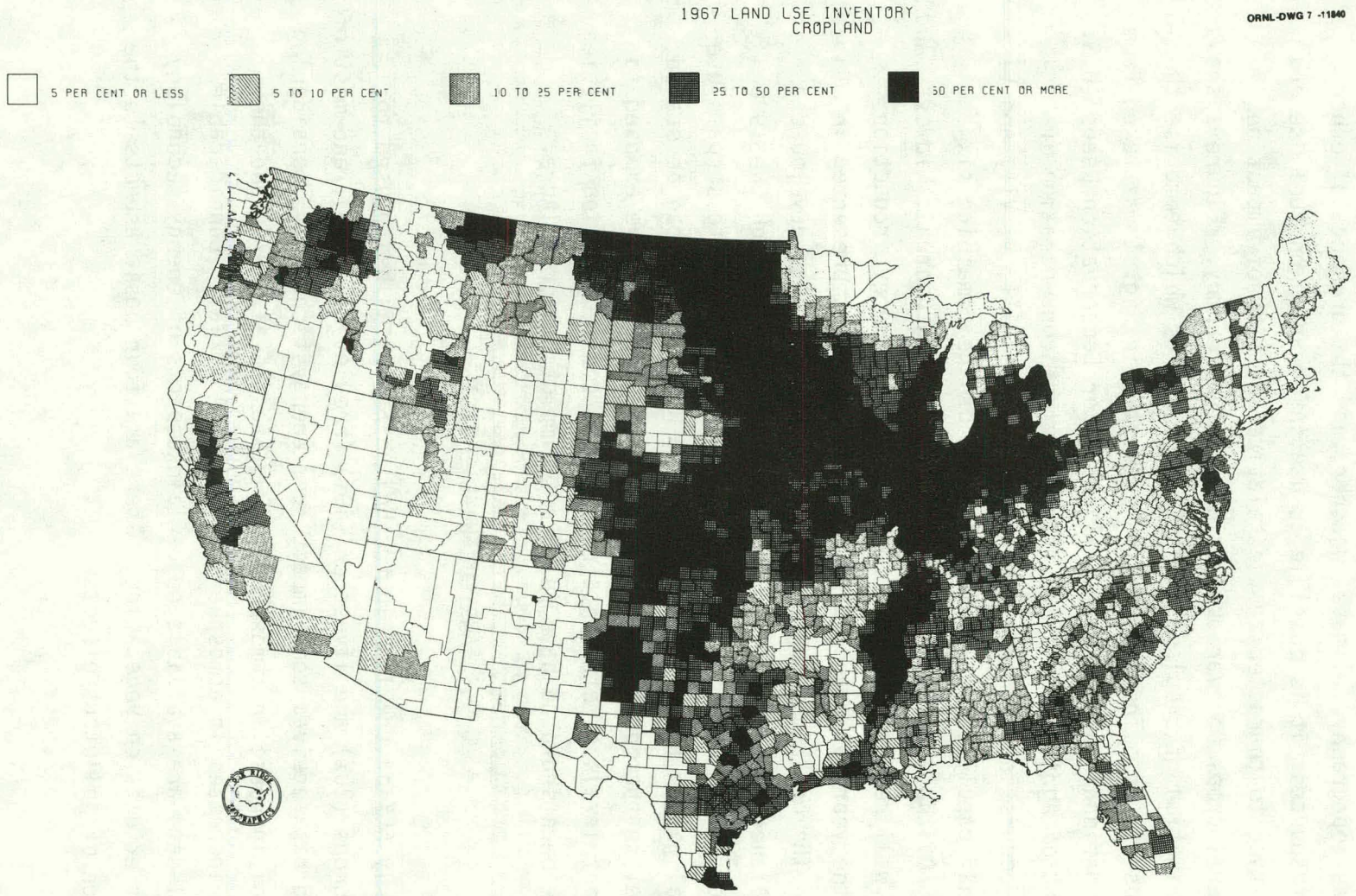

Fig 1. Distribution of croplands in the 48 contiguous states of the United States of America (generated from the Geoecology Data Base, ORNL).

(1) Pollutant. Pollutant is a generic word denoting a chemical or group of chemicals which may act alone or synergistically in their effects on receptors. The chemical released from a source may not be the same pollutant near the receptor because complex chemical changes may occur during transport in the atmosphere.

Pollutant composition and concentration will depend on a number of variables such as source characteristics (including type, size, dimension, and location in relation to the location of the vegetation) and the amount of emissions and their effluent velocity and temperature. Plant response to pollutants depends on such properties as chemical composition, physical state, coexisting pollutants, and rate of transfer to the receptor. Consideration must also be given to the concentration of the pollutant near the receptor, its solubility, duration of exposure time, and the frequency distribution of periods of known duration and concentration.

(2) Environment. Environment considerations include meteorological data, climatic factors (such as temperature, relative humidity, light quality and intensity, photoperiod), and such factors as soil temperature, moisture, mineral content, and CO_2 concentration.

(3) Receptor. The receptor may be a plant canopy, a whole plant, or a part of a plant (such as a leaf or its roots) or some fine structure of its cells (such as cell membranes, chloroplasts or mitochondria), or it may be some physiological system within the cells relating to enzyme or hormone control. The receptor may be characterized by its biological organization, species, variety, and genotype, by its structure and relation to its environment under normal conditions, and by its susceptibility to injury by pollutants, age, and state of health, as well as previous exposures.

(4) Event. An event may be described as a change in the character of the receptor in response to a pollutant under the existing environmental conditions.

Factors Affecting Plant Response

Aside from variations in environmental conditions which influence the sensitivity of plants to phytotoxic air pollutants, there are other considerations of importance, such as the number and condition of stomata, the solubility of pollutants, and the species and individual susceptibility of the plants.

Stomata. Pollutant injury depends on entry through the stomata. Conditions which favor open stomata at the time of exposure predispose the plant to injury. As an example, concentrations of SO_2 in the range of 0.1 to 0.5 ppm stimulated stomatal opening (Unsworth et al. 1972). Such stimulation could be particularly relevant in cases of synergism of other pollutants with SO_2 because SO_2 can stimulate stomatal opening, facilitating the entry of other air pollutants. Water stress causes stomata to close and reduces plant pollutant uptake.

Temperature. Above a critical temperature of 5 C, SO_2 injury to plants increases (Wood 1968).

Humidity. Plants are more susceptible to injury as the relative humidity increases (Wood 1968).

Soil moisture. There is an increased resistance of plants to SO_2 as the soil moisture reaches the wilting point (Wood 1968).

Solubility of pollutant. Factors which affect absorption relate directly to the accumulation of toxic substances in plants and their subsequent potential injury. In general, the plant uptake rate increases as the solubility of the pollutant increases. A model for gaseous exchange between the atmosphere and a vegetation canopy should include solubility and reaction rate parameters. Highly soluble pollutants could produce high solute levels, depending on the plants' capacity to use, change, or translocate the polluting gas. It would be useful to be able to relate internal pollutant concentrations to external atmospheric concentrations. The solubility of SO_2 in water is 228 g/liter at 0°C. This is equivalent to dissolving 50 volumes of SO_2 in 1 volume of water. Bennett et al. (1973) has tabulated the solubility of several air pollutants (Table 7).

Table 7. Solubilities of selected gases in water at 20°C (Bennett et al. 1973)

Gas	Solubility (m moles gas absorbed per ml H_2O @ P_{gas} = 1 atm)
CO	0.0010
O_2	0.0014
NO	0.0021
O_2	0.012
CO_2	0.039
Cl_2	0.10
SO_2	1.6
HF	18

Susceptibility. The most sensitive agricultural plants tend to have succulent leaves and high growth rates. In the case of SO_2, susceptible species may be damaged by an 8-hr exposure to concentrations from 0.05 to 0.5 ppm. For shorter term exposures (30 min), the concentration must be raised to 1 to 4 ppm to obtain a plant response, whereas species that are resistant will require 2 ppm for 8 hr, or 10 ppm for 30 min. These effects may be greatly altered in the presence of other pollutants (Mudd 1975).

Susceptibility lists of plant responses to pollutants are available but should be used only as a guide. Variations in responses can occur due to differences in geographical location, climate, and plant stage of growth and maturation. For example, alfalfa, barley, endive, and cotton were most sensitive to SO_2 in the study of Thomas and Hendricks (1956), with privet being 15 times more tolerant than these sensitive species. Zahn (1961) showed that clover-type fodder plants were most sensitive to SO_2, whereas wheat, leafy vegetables (excluding cabbage), beans, strawberries, and roses were moderately sensitive, and root crops and cabbage were least sensitive.

Of plants susceptible to SO_2 in British Columbia, Canada (based on field observations and fumigation experiments), larch, birch, ninebark, alfalfa, and lettuce were most sensitive, and red cedar, silver maple, spirea, field corn, and asparagus were most tolerant (Katz et al. 1939).

Of cultivated plants and native forest trees susceptible to SO_2 (based on field observations), buckwheat, red clover, trembling aspen, jack pine, eastern white pine, white birch, and bracken fern were most sensitive, and cabbage, corn, white spruce, and sugar maple were most tolerant (Dreisinger 1965).

Ten plants that occur commonly throughout the United States were selected and their sensitivity to SO_2 determined in fumigation experiments. Chickweed was most sensitive; mustard, annual bluegrass, sunflower, Kentucky bluegrass, pigweed, and cheeseweed were intermediate in their sensitivity; and lambs' quarters, dandelion, and nettleleaf goose-foot, tolerant (Benedict and Breen 1955).

Pollutant Injury to Plants

Acute injury in which symptoms of injury are visible

Chlorosis, necrosis, abscission of plant parts, and effects on pigmentation are examples of acute injury with visible symptoms. These symptoms may be produced by high concentrations of SO_2, PAN, HF, O_3, ethylene, or combinations of these substances (Taylor 1973). For photographs of SO_2 damage to plants, see Jacobson and Hill (1970).

Invisible injury

It has been shown that crops with no visible injury may suffer up to 50% reduction in growth and yield (Schuck 1973). Even though visible injury is not apparent, symptoms of chronic injury (due to repeated exposure to low levels of air pollutants) are manifested by decreased growth, faster aging of foliage, reduction in photosynthesis and in dry weight, reduced leaf size, stem length, root weight, and flower production, as well as a delay in the onset of floral initiation (Feder 1973). In order to evaluate the impact of air pollution on agricultural productivity one must consider both the acute and chronic dose response. The most pervasive air pollutants currently affecting agricultural production are ozone and sulfur dioxide. If present levels in the eastern part of the country should double, major yield reductions of important agronomic crops could result (Heck 1973). The issue is not completely resolved because there are studies that show yield reduction only in association with visible injury (Hill and Thomas 1933).

The emission of SO_2 and NO_2 into the atmosphere from fossil fuel combustion is followed by chemical transformation and acid rainfall, particularly over the eastern United States, with a resulting increase in damage to vegetation. Some effects include (1) reduced photosynthesis; (2) accelerated weathering of protective surface waxes of leaves on both forest and agricultural plant species; (3) increased leaching of nutrients from the leaves of plants and from the soil (most soils have only a finite capacity to buffer acidic leachate);

(4) increased solubility of toxic metals making them more liable to translocation through the plant; (5) inhibited nodule formation on root systems of legumes making them more susceptible to disease; and (6) interference with mycorrhizae. Since some level of pollutant control is expected to be used in the production of energy, the effects of chronic exposure of plants to low levels of pollutants will probably be more relevant to the determination of impacts from the emissions of power plants than high levels producing acute effects.

Dose-response-symptomology relationships for SO_2 as a single pollutant have been well documented. However, most plants grow in open fields and are subjected to exposure to multiple pollutants simultaneously. This may result in more damage than that which would result from the sum of the damage caused by each one acting alone.

The ubiquitous nature of air pollutants makes it a difficult task to pinpoint sources and also to find unpolluted control sites. Foliar injury alone is no longer sufficient to describe plant response to pollutant stress. A reduction in photosynthesis and growth may occur in growing plants before visible symptoms appear, or the rate of photosynthesis may be altered (Mudd and Kozlowski 1975; Bennett et al. 1973). Pollutants may react with cell constituents, disrupting their structural, metabolic, or functional integrity (Mudd and Kozlowski 1975; Wellburn et al. 1972). Among those effects not readily discernible may be those of a physiological or biochemical nature, such as effects on pyrimidines and inactivation of enzyme systems (Mudd and Kozlowski 1975; Ma et al. 1973). Studies at the molecular level are detailed in the book "Responses of Plants to Air Pollution" (Mudd and Kozlowski 1975, pp. 9-22).

Sulfur dioxide has received little mechanistic study by plant physiologists and biochemists, with the result that we cannot yet describe in detail the sequence of events leading to the characteristic response of the plant to this pollutant. Wood (1968) has pointed out that a high degree of correlation between SO_2 concentration and severity of vegetation damage, regardless of the level of statistical significance, does not alone establish cause and effect.

Among the methods that are used to determine the effects of pollutants on plants are inhibition of photosynthesis and crop yield. One of the methods for determining inhibition of photosynthesis is by determination of CO_2 and O_2 exchange rates of plants. Change in net CO_2 assimilation and respiration can be sensitive indicators of pollutant effects on the productivity of plants (Daines 1968). Bennett and Hill (1974) present some responses of alfalfa to common air pollutants (Table 8).

Dose-Response Relationships

A number of terms can be used to describe the characteristics of a response; threshold is one. According to O'Gara (1922), however long the exposure time, no damage will occur below a threshold dose, but above that dose, damage can be produced by combinations of concentration and length of exposure time. He used the following equation to describe the conditions for the development of SO_2 damage to plants:

$$(C-C_R)t = K \quad ,$$

where C = concentration of pollutant, C_R = threshold concentration for injury, t = time in hours required to initiate damage, and K = constant, the threshold dose.

The criterion most publicized is that if the 8-hr concentration of SO_2 does not exceed 0.25 ppm, injury to vegetation will seldom occur (Linzon 1972). Concentrations of 0.35 ppm for 4 hr, 0.55 ppm for 2 hr, and 0.95 ppm for 1 hr are considered potentially damaging to vegetation. Chronic or acute injury may occur during the growing season at average annual concentrations of 0.03 ppm or over in the vicinity of stationary sources. Fumigation experiments and field surveys support the above criteria (Brisley et al. 1959; Katz et al. 1939; Linzon 1958).

Table 8. Inhibition of photosynthetic rates of alfalfa by 1-hr treatments with various pollutants and combinations of the pollutants (from Bennett and Hill 1974)

Pollutant(s)	Conc. (pphm)	n	$\overline{\Delta P}$(% control)[a]
O_3	10	5	4 ± 3
	20	5	10 ± 4
SO_2	15	5	0
	25	15	2 ± 1
	30	5	6 ± 3
	50	10	21 ± 3
NO_2	25	13	0
	40	5	2 ± 2
	50	5	3 ± 3
HF	3	5	3 ± 2
SO_2+NO_2	(15 + 15)	5	7 ± 2**
	(25 + 25)	13	9 ± 2**
	(50 + 40)	7	20 + 4
SO_2+O_3	(30 + 10)	5	11 ± 3
	(30 + 20)	5	19 ± 4
SO_2+HF	(25 + 3)	5	9 ± 3*
NO_2+HF	(50 + 3)	5	7 ± 3
NO_2+O_3	(50 + 10)	3	9 ± 4

[a]Mean depression ($\overline{\Delta p}$) in CO_2 uptake rates induced after 1-hr exposures, and 95% confidence interval. (Superscripts ** and * denote those significant means at 1% and 5% significance levels, respectively, when compared with the summed depressions determined for the separately applied pollutants at corresponding concentrations.)

This report is not an exhaustive review of the literature nor a detailed description of all the possible dose-response relationships. Such relationships may be found in the references used in this paper and in the following special references whose authors have reported either their own work or compiled data from the literature.

(1) Summary of data on exposure of plants to SO_2. (Wood 1968)

(2) Response of horticultural crops to SO_2 and O_3 mixtures. (Reinert et al. 1975)

(3) Plant response to SO_2 and NO_2 mixtures. (Reinert et al. 1975)

(4) Plant response to SO_2 and HF mixtures. (Reinert et al. 1975)

(5) Crop, ornamental, and forest species in which variation in sensitivity to the pollutants named has been observed. (Ryder 1973)

(6) Sensitivity of woody plants to SO_2 and photochemical oxidants. (Davis amd Wilhour 1976)

(7) Maximum ranges of annual average SO_2 concentrations tolerable to lichens and bryophytes. (Le Blanc and Rat 1975)

Beneficial Effects

Many products from energy technologies can be used to increase agricultural productivity. Waste heat may be used to heat greenhouses and soil and can also be used to dry agricultural products. Sulfur is an essential element in plant and animal growth, and the SO_2 releases from coal combustion facilities may alleviate sulfur deficiency in some grassland and cropping areas. Saline water from cooling towers (blowdown) could be used to irrigate agricultural crops without detrimental effects if careful irrigation management is maintained. It is clear, however, that these benefits are rather specialized and overall energy technology effluents would probably result in degradation of the environment without suitable controls.

COMMENTARY ON AGRICULTURAL MODELS

The blossoming of simulation modeling from the mid-1960s has produced a large number of models of a diverse range of phenomena in many varied disciplines. Evaluation of these efforts in terms of specific needs or questions can be made through detailed examination of available documentation and model application reports. This survey attempts a more general evaluation in terms of possible model applications for the assessment of any energy technology impacts on agricultural ecosystems. Two hundred references were reviewed from a computer search of the following data bases: EEDB - ERDA Energy Data Base, GRA - Government Reports Announcements, BA - Biological Abstracts, BRI - Biological Research Index, CAIN - National Agricultural Library, and CBALL - Chemical and Biological Activities. Retrospective searches were conducted initially in April 1976 and periodic searches were continued until January 1978 with the following key word matrix:

Group I agriculture, agronomy, irrigation, soil, plant, litter, root, leaf, growth, corn, wheat, soybean, forage.
Group II model, computer simulation, simulation, mathematical, code.

Key words were expanded to include related terms such as crop, stomata, photosynthesis, grass, pasture, cotton, evapotranspiration, water, radiation, and vegetables.

Cross codes - Each reference included in Biological Abstracts is grouped into category and the category given a number. We searched the relevant numbered categories combined with key words in Group I and Group II. The coded numbers themselves were included with Group I.

Code numbers and categories used in this search: 07506P - plant ecology; 51502P - water relations; 51510P - cell growth and differentiation; 51516P - radiation effects (light effects); 51524P - apparatus and method for plant physiological studies; 525 - agronomy; and 53008P - vegetables.

Search logic - Group I and Group II were combined.

Relevant references were obtained and reviewed. More recent information was obtained through correspondence with several of the well-established modeling groups in the United States and overseas.

This task remains unfinished in view of the continuing development and use of models for agricultural ecosystems. The survey contains information that is predominantly obtained from open literature. The modeling reports published by institutions were reviewed as much as possible. However, there is probably considerable information that was not detected by the computer search mechanism.

Other reviews of modeling literature were also examined. These sources, although different in purpose, are outlined in a later section with comments about the relevance of these reviews to the assessment of energy technology impacts in agriculture.

General Comments

A wide range of models was examined in which the complexity increased from mathematical functions fitted to experimental data, through parametric models that described phenomena without representation of mechanisms to mechanistic models based on physical, chemical, and/or physiological principles. The empirical and parametric models are restricted in their application to situations that closely resemble that for which the model was calibrated. Alternatively, field measurements can be made in a new situation to determine appropriate parameter values. The mechanistic models also require input values for the appropriate soil, plant, animal, or atmospheric properties as required by the mechanisms or processes involved. These latter models can conceptually be applied to most locations, whereas the empirical models are local or at best regional in their range of application.

The model evaluation (Appendix A) contains the full citation and the authors' abstract along with the identification of the type of model (MODEL TYPE) and a comment (COMMENT) about the suitability of the model for assessment of energy technology impact in agriculture. The model type is described by one of the following classes.

(1) Mechanistic. Model based on physical, chemical, and/or physiological principles as appropriate. In some instances the physiological principle may be simplistic; for example, the use of Ohms law to represent transport processes.

(2) Statistical. Model based on correlation, regression, or least-squares fit of observations to a given function.

(3) Stochastic. Model based on algorithm response to random variables derived from studies of event probabilities.

(4) Parametric. Model represented by a phenomenological function with parameters determined from analysis of empirical data without direct representation of the mechanisms involved.

Several papers provide program code listings, particularly those using IBM continuous system monitoring program (CSMP). However, this is the exception and it is anticipated that considerable effort would be involved in the application of the models by developing computer codes for the algorithms or through implementation of the original code obtained from the author. A further complication is also anticipated in that most models would require some adaptation for technology assessment. In the simplest case, an empirical relationship between some impact (technology origin) and an agricultural response would be required to be added to the models. This fact identifies the need for experienced input from personnel familiar with both modeling and dose-response or cause-effect relationships to extend the use of models to examine environmental effects of technology impacts. The dominant impacts of energy technology on agriculture through 1990 will be from coal combustion effluents, particularly air pollutants. However, there are relatively few models of air pollutant-crop interactions identified in the bibliography even though there is a considerable empirical data base of pollutant effects on crops.

Other Model Reviews

Several review reports on aspects of modeling were identified in our survey, and although their goals were different than the present goals, these sources provide valuable information about models and modeling.

File of Agricultural Research Models (FARM)

The U. S. Department of Agriculture has an active file of models that is currently maintained by Dr. Bruce Crane, Room 408, Nal Building, Beltsville, Maryland 20705 (phone 301/344-3937). We obtained a copy of the fourth release (November 1977) which contained an inventory of 111 models, many of which can be adapted for technology assessment purposes. Many of these models are not included in the present model survey, and the FARM document should be viewed as a resource for the modeling of technology impacts in agriculture.

Agricultural Systems Models and Modeling: An Overview

A review paper with the above title by G. M. Van Dyne and Z. Abramsky was published in 1975 in "Study of Agricultural Systems," (G. E. Dalton (ed.), pp. 23-106, Applied Science Publishers Ltd., London). Eighty-eight models were examined in the following categories: dairy 12, pest control 6, irrigation 1, fishery 3, wildlife 8, grazing 33, plant growth 25. Many linear programming-optimization models have been developed as aids in decision-making in various aspects of dairy operations. Many of the grazing models simulate plant growth and animal production and could be adapted to technology assessment by inclusion of representative dose-response algorithms. It is clear that in many instances available models cannot be applied directly to technology assessment.

Mathematical Models in Plant Physiology

J. H. M. Thornley published a volume (Academic Press, New York, 1976, 318 pp.) that largely provides a compilation of his own modeling research conducted during the previous decade. Many of these models are outlined in Appendix A. Thornley's modeling research has been directed towards physiological research and a significant amount of modification would be required for application in technology assessment.

Survey of Crop-Weather Models

D. B. Johnson reviewed 24 models in some detail for a MS Thesis in the Department of Meteorology, Pennsylvania State University (1976). He identified two main types of models: statistical and simulation. The former type has the same meaning as used in this document, while the simulation type includes parametric and mechanistic types as defined in this report. Models for wheat, maize, oats, soybeans, and sorghum were examined. The statistical models are restricted in their range of application to the soil, plant, and weather regime for which they were developed. These codes and the simulation types all require some adaptation for the technology assessment.

Survey of radionuclide Transport and Dosimetry Models

HOFFMAN, F. O., C. W. MILLER, D. L. SHAEFFER, and C. T. GARTEN. 1977. Computer codes for the assessment of radionuclides released to the environment. Nucl. Saf. 18:343-354.

Abstract

This article presents a compilation of computer codes that may be used for the assessment of accidental or routine releases of radioactivity to the environment from nuclear power facilities. The capabilities of 83 computer codes in the areas of environmental transport and radiation dosimetry are summarized in tabular form. This preliminary analysis clearly indicates that the initial efforts in assessment methodology development have concentrated on atmospheric dispersion, external dosimetry, and internal dosimetry via inhalation. The incorporation of terrestrial and aquatic food-chain pathways has been a more recent development and reflects the need for satisfying the current requirements of environmental legislation and the needs of regulatory agencies. The characteristics of the conceptual models employed by these codes are reviewed. (Auth.).

Other Review Topics

Several articles and monographs on particular aspects of modeling are outlined below.

HESKETH, J. D., and J. W. JONES. 1976. Some comments on computer simulations for plant growth. Ecol. Model. 2:235-247.

Abstract

The status of plant growth modeling activities is reviewed for a general audience. Recently, excellent textbooks and review papers have been published which summarize past efforts in modeling plant physiological processes. Anyone interested in plant-growth modeling should be aware of this background material which describes the modeling tradition in the plant sciences. Presently, we need better critical evaluations of such models, including experimental techniques necessary for generating associated data. Such critiques should be aimed at users of large plant-growth models in other disciplines. Recent developments in the construction of cotton growth models are described. Modeling philosophy is discussed in relation to the above. (Auth.).

LEMEUR, R., and B. L. BLAD. 1974. A critical review of light models for estimating the shortwave radiation regime of plant canopies. Agric. Meteorol. 14:255-286.

Abstract

A general review of geometrical and statistical light models is presented in this paper. In the geometrical approach, plant shapes are simulated by various geometrical forms described by characteristic dimensions. Geometrical models may be divided into two classes - those which consider individual shapes and those which consider an arrangement of shapes. In the statistical approach the location of plant elements is parameterized by various distributions. The type of leaf dispersion in space is the most important consideration in statistical models. Four different types of leaf dispersion are considered in this review: regular leaf dispersion, clumped leaf dispersion, random leaf dispersion, and variable leaf dispersion.

Hypotheses which underlie the various random and more generalized types of statistical light models are presented. Several models in the literature are discussed in terms of these assumptions.

Although, in many cases, required plant data and actual light measurements in the field are grossly inadequate for experimental verification of light models, it appears that the light regime in plant canopies can be adequately described by those models already available. However, for the most part, these models are very complex, and a synthesis of these fundamental models into workable expressions that can be used by agronomists, crop ecologists, and others concerned with breeding plants for more efficient interception of light is needed. (Auth.).

MONSI, M., Z. UCHIJIMA, and T. OIKAWA. 1973. Structure of foliage canopies and photosynthesis. Annu. Rev. Ecol. Syst. 4:301-327.

Abstract

It is apparent from this review of the vast amount of research work on the problems of canopy structure and photosynthesis that our understanding of canopy photosynthesis has been considerably deepened by the activities of IBP during the recent decade. The results obtained have been successfully used in breeding programs towards developing high yielding crops with erect leaf plant types. The results are also interesting and valuable for assessing the photosynthetic productivity of plants - upon which virtually all life on earth depends.

A salient result from recent studies on canopy structure and photosynthesis has been the development of production models based on the theoretical and empirical laws of the major exchange process of energy and materials between plants and their environment. Special attention has been given to models dealing with light interception and photosynthetic relationships. Such light interception models have provided the mathematical procedure for the assessment of productivity not only of agricultural plant ecosystems but also of natural plant ecosystems, revealing that leaf inclination plays an important role in the photosynthetic productivity of plant canopies. These models have also been remarkably successful in clarifying plant behavior at the ecological level.

In relation to the interception of light by plant canopies, many attempts have been made to measure or formulate canopy structure. These studies made it possible to distinguish the canopies observed in natural and agricultural ecosystems into four types. Canopy structure data from field plantings of crops have been used to simulate the radiation environment and the photosynthesis of plant canopies. However, our information on the phytometric features of plant canopies, including the allocation of photosynthate, has not been as comprehensive as might be desired.

The development of computer technology has greatly facilitated the study of the interactions of plant communities with environmental factors. Although the computer simulation of plant growth seems to have success in integrating knowledge obtained in related disciplines, our efforts in exploring the biological and physical processes involved in plant photosynthesis have not yet necessarily been profound enough. The available information and working models of the relationships of photosynthesis and the environment are still meager and fragmentary. Particularly, the deficiency is greater for forests including fruit tree orchards than for crops with uniform plant

stands of relatively low height. Many problems thus remain to be studied.

Attempts to make clear the phytometric characteristics and biological behavior of plant canopies under various environmental conditions and to refine the working models appear to be equally important for improving biophysical simulation of canopy photosynthesis and dry-matter production of plants. Such efforts should necessarily facilitate the increase in man's knowledge on the processes related to forecasting and controlling plant production. (Auth.).

WALKER, W. R. 1976. Assessment of irrigation return flow models. EPA-600/2-76-219. Robert S. Kerr Environmental Research Laboratory, USEPA, Ada, Oklahoma.

Abstract

Throughout the western United States irrigation return flows contribute to the problem of water quality degradation. Evaluating the effectiveness of alternative management strategies involves models which simulate the processes encompassed by irrigated agriculture. The development and application of these models require multidisciplinary expertise. A workshop involving fifteen specialists in the varied aspects of irrigation return flow modeling was held to review the status of these models. Irrigation return flow and conjunctive use models recently developed by the Bureau of Reclamation served as focal points for the workshop. As the field verification and potential applications of these models were discussed, several general problems were identified where further investigation is needed. Particular emphasis was given to the description of the spatially varied aspects of soil, crop, and aquifer systems, and the proper alignment of model objectives with available data. The large number and diversity of existing models illustrate the individualistic nature of irrigation return flow modeling. In order to effect more widespread utilization of existing models, a systematic procedure should be developed to update and disseminate this modeling technology. (Auth.).

Pudoc Publications

The Centre for Agricultural Publishing and Documentation, P. O. Box 4, Wageningen, The Netherlands, has published the following simulation monographs:

(i) de Wit, C. T., and H. van Keulen. Simulation of transport processes in soils.

(ii) Beek, J., and M. J. Frissel. Simulation of nitrogen behavior in soils.

(iii) de Wit, C. T., and J. Goudriaan. Simulation of ecological processes.

(iv) Fransz, H. G. The functional response to prey density in an acarine system.

(v) Frissel, M. J., and P. Reiniger. Simulation of accumulation and leaching in soils.

(vi) van Keulen, H. Simulation of water use and herbage growth in arid regions.

(vii) Makkink, C. F., and H. D. J. van Heemst. Simulation of the water balance of arable land and pastures.

Each monograph is the result of a few years' theoretical and experimental work and contains a full presentation of the simulation programs, preprogramming difficulties, and justification of assumptions with an emphasis on verification.

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APPENDIX A

AGRICULTURAL MODELS

APPENDIX A
Agricultural Models (continued)

<1>
Aase, J.K., J.R. Wright, and P.H. Siddoway. 1973. Estimating soil water content on native rangeland. Agric. Meteorol. 12:185-191.
ABSTRACT: A model for estimating soil water content on native rangeland was tested at Sidney, Montana. Based on the Penman combination method for estimating potential E", the model includes factors to account for crop development, limiting soil water content, and increased evaporation after rain. The model gave reasonable estimates of actual soil water conditions within a 15% limit suggested as being practical for rangeland management purposes. (Auth.)
MODEL TYPE: mechanistic with empirical factors
COMMENT: Model is a practical management tool that requires tuning for a particular application. The model could be used as a component of a rangeland impact assessment.

<2>
Aikman, D.P., and W.P. Anderson. 1971. A quantitative investigation of a peristaltic model for phloem translocation. Ann. Bot. 35, 761-772.
ABSTRACT: An analysis is made of a peristaltic model of phloem translocation. It is postulated that the periodic action of contractile or bending organelles drive a longitudinal flow of solution within tubules which connect sieve pores in successive sieve plates. Plausible values are assumed for the velocity of propagation of the contraction wave, the frequency, the amplitude, and the viscosity of the solution and its concentration. Using relations which describe peristaltic flow, predictions are made for the values of parameters such as the velocity of solution, the driving pressure, and rate of energy dissipation. These predicted values are seen to be reasonable when compared with the known properties of other biological contractile systems. Thus the model is quantitatively acceptable. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Theoretical model of a plant process. Not useful in technology assessment.

<3>
Alderfer, R.G., and D.M. Gates. 1971. Energy exchange in plant canopies. Ecology 52:855-861.
ABSTRACT: A theoretical model is presented for the exchange of radiant and sensible heat between leaves in a plant canopy and the environment. The distribution of short-wave (0.3-3.0 micron) radiation in a canopy is described by a modified form of the Kubelka-Munk equations for light transmission through scattering media. Upward and downward radiation fluxes are computed for any level of a canopy as a function of canopy density and optical properties of the leaves. A series of simultaneous equations is used to determine both thermal radiation and leaf temperature at any point in the canopy. Each equation in the series is the energy budget for a leaf at that level in the canopy. This model uses information about the external physical environment together with optical properties of leaves to predict the distribution of solar radiation, leaf temperature, and thermal radiation throughout a plant canopy. Experiments are reported which test the reliability of the theoretical model. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This is a basic model of a canopy energy budget. Could be used to evaluate effects of change in canopy optical properties that may be induced by acid rain or pollutant uptake.

<4>
Alessi, J., and J.P. Power. 1965. Influence of moisture, plant population, and nitrogen on dryland corn in the northern plains. Agron. J. 57:611-612.
ABSTRACT: The effects of total available soil moisture, plant population, and N fertilization upon dryland corn production were studied at 2 locations over a 6-year period. Forage and grain yields were highly correlated with total available moisture (soil moisture at planting plus precipitation). Optimum population at each location was 10,000 plants per acre. Applications of N were of little benefit. (Auth.)
MODEL TYPE: statistical - regression equations
COMMENT: Model is site specific to Sidney, MB and Mandan, ND. Probably of little use in technology assessment.

<5>
Allen, L.H. 1974. Model of light penetration into a wide-row crop. Agron. J. 66:41-47.
ABSTRACT: This model predicts direct-beam radiation penetration into wide-row crops. The crop is modeled as "hedge-rows" with an open middle between the rows. Leaf area density is given height and cross-row functional distributions, but is considered uniform along the length of the row. Input parameters which can be varied are: time of day, time of year, latitude, longitude, atmospheric transmissivity, slope of the soil surface, row direction, row spacing, crop height, width of the hedge-row, leaf area density distribution functions, and mean leaf angle. The model can predict the average direct-beam penetration to any depth as a function of distance from the row, and the average penetration for the whole hedge-row system. Light penetration was predicted for E-W, N-S, NE-SW, and NW-SE, row orientations for August 17, 1967, using row geometry of E-W wide-row grain sorghum (SORGHUM BICOLOR L. Moench) grown at Akron, Colorado. Low predictions of light interception in the morning and afternoon by E-W rows resulted in the lowest predictions of daily total intercepted light. Under the input conditions, the model predicted 37, 44, 42, and 42% daily interception for E-W, N-S, NE-SW, and NW-SE row orientations, respectively. The NE-SW row orientation may be best since the model predicted that the most light would be absorbed at 1000 hours, when moisture stress would be low, and the least at 1400 hours, when moisture stress would be high. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be used to evaluate fog or plume shading effects on row crop radiation regime.

<6>
Allen, L.H. 1975. Line-source carbon dioxide release, III. Predictions by a two-dimensional numerical diffusion model. Bound.-Layer Meteorol. 8:39-79.
ABSTRACT: Model predictions of CO(2) concentrations downwind from a line source were calibrated using experimental data. Agreement between the model and experimental data was improved by adjusting for wind direction meander and cup anemometer overshoot. The model predictions showed that by using a negative exponential wind speed profile within the crop canopy, predictions were closer to observed CO(2) concentration profiles than when experimentally observed wind speed profiles, which were constant with

APPENDIX A
Agricultural Models (continued)

<6> CONT.
height in the lower canopy, were used. This finding suggests that much of the lower canopy airflow was not direct mass flow in the downwind direction. Eddy diffusivity profiles which showed a within-canopy local minimum resulted in a restriction in the predicted loss of CO(2) out of the canopy system. Two-dimensional plots of predicted null vertical flux and CO(2) concentration portrayed vividly the turbulent diffusion and mass flow transport of CO(2) from the line source. (Auth.)
MODEL TYPE: mechanistic - 2D numerical solution
COMMENT: Model requires experimental calibration. Method could be used for assessing gas pollutant or gas fertilizer transport.

<7>
Allen, L.H., and K.W. Brown. 1965. Shortwave radiation in a corn crop. Agron. J. 57(1):575-580.
ABSTRACT: Near-infrared and total shortwave radiation were measured at various heights in corn using Japanese EKO solarimeters, with and without appropriate light filters. From these measurements, visible radiation was calculated. The resulting data indicated that the attenuation coefficients for radiation within this crop were not constant. Near-infrared radiation was found to be a higher percentage of the total shortwave radiation at the bottom of the crop than at the top. (Auth.)
MODEL TYPE: mechanistic with empirical parameters
COMMENT: Paper describes a relatively simple model requiring four averaged radiation measurements to implement for a plant community. Effects of change in crop reflectivity can be evaluated.

<8>
Allen, L.H., H.W. Gausman, and W.A. Allen. 1975. Solar ultraviolet radiation in terrestrial plant communities. J. Environ. Qual. 4:285-294.
ABSTRACT: There has been a growing concern that NO(x) effluents from supersonic or other highflying craft, or chlorofluoromethane refrigerants or aerosol can propellants that diffuse to the stratosphere, could cause a reduction of atmospheric ozone, which would result in a concomitant increase of penetration of solar ultraviolet radiation to the earth's surface with possible biological consequences. Spectral distributions of direct-beam and diffuse solar ultraviolet irradiance at the earth's surface, as a function of stratospheric ozone content and solar elevation angle, have been accurately measured or predicted by other researchers. Our objectives were to couple incident spectra to a plant canopy radiation penetration model to give the redistribution of middle ultraviolet radiation, or UV-B (280-315 nm), within plant canopies. Detailed comparisons were made between two ozone content conditions (0.32 cm, typical for 30 deg. N latitude and 0.24 cm, representing a 25% ozone reduction) with a 60 deg. solar elevation angle. Predictions of UV-B radiation regimes in plant communities over ranges of architectural or structural characteristics, including erect leaf, normal leaf, and horizontal leaf canopies, were computed. Clumped, random, and regular leaf distributions were modeled, as well as leaf area indices of 2.6, 3.3, and 4.0. Phyloelement optical properties included zero transmissivity and 5% reflectivity. Soil reflectivities of both 5% and 20% were used. Epidermal transmission spectra were used to predict UV-B radiation loads inside leaves. Predicted penetration of UV-B radiation was much greater in erect-leaf than horizontal-leaf canopies. Upward-directed UV-B irradiance was greater near the ground level than near the top of the canopy. In conclusion, the model prediction described the range of UV-B radiation regimes to be expected in plant communities under present stratospheric ozone content and under a 25% ozone reduction. Data from these idealized plant communities can be interpolated for other plant canopy types and soil types to predict upward or downward UV-B radiation loads and dosages. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This is an application of the SPAM model described by Lemon, D.W.; Shawcroft, R.W. (1971). The sun's work in a corn field. Science 174: 371-378. The SPAM model could be extended to evaluate UV impacts on other terrestrial ecosystems.

<9>
Allen, L.H., S.E. Jensen, and E.R. Lemon. 1971. Plant response to carbon dioxide enrichment under field conditions: A simulation. Science 173:256-258.
ABSTRACT: A comprehensive soil-plant-atmosphere computer simulation model (SPAM) predicted up to a 45% increase in carbon dioxide uptake by a crop enriched with carbon dioxide at ground level. Enrichment rates of 225 and 450 kilograms of carbon dioxide per hectare per hour were used. Simulations covered a wide range of wind speed, crop height, and leaf area display. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Application of the SPAM model - This study assesses the possible impact of elevated CO(2) levels on plants.

<10>
Allen, L.H., D.W. Stewart, and E.R. Lemon. 1974. Photosynthesis in plant canopies: Effect of light response curves and radiation source geometry. Photosynthetica 8(3):184-207.
ABSTRACT: A soil-plant-atmosphere computer simulation model (SPAM) was used to study the sensitivity of plant canopy photosynthesis to leaf irradiance response curves and to diffuse sky-sources of radiation. Twenty photosynthetically active radiation (PhAR) loaded classes on leaf elements in 15 layers of a plant canopy were computed. The direct-beam radiation load on leaves was distributed as a broad band rather than as a sharp peak because leaf elements were oriented at various angles with respect to the normal to the solar beam. The predicted canopy photosynthesis was influenced strongly by the shape of the leaf irradiance response curve at low levels of PhAR, since much of the leaf material was exposed to diffuse radiation only. The model predicted that a high percentage of diffuse sky-source radiation would increase total canopy photosynthesis, even when we accounted for the overall decrease in global PhAR. This latter finding implies that cloudy or overcast days may not be a serious detriment to total canopy photosynthesis in some species, and that heavy haze may actually enhance canopy photosynthesis in species with low photosynthetic capacity. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Sensitivity analysis of a soil-plant-atmosphere model (SPAM). Model is well tested and could be used to evaluate effects of microclimate and physiological changes produced by an energy technology on agricultural crops.

APPENDIX A
Agricultural Models (continued)

<11>
Allen, W.H., and J.R. Lambert. 1971. Application of the principle of calculated risk to scheduling of supplemental irrigation, II. Use on flue-cured tobacco. Agric. Meteorol. 8:325-340.
ABSTRACT: A simulation model was constructed to test the application of an irrigation-scheduling decision model which incorporated the basic concepts of calculated risk. Inputs for the model included: (1) the official probability precipitation forecasts for the periods "today", "tonight" and "tomorrow"; (2) initial soil moisture content; (3) daily precipitation; (4) daily mean temperatures; (5) daily potential evapotranspiration and daylength values; (6) functions relating existing soil moisture content and stage of growth to the corresponding damage done to the crop; and (7) cost of irrigation. The loss functions were developed specifically for flue-cured tobacco. Two methods were used for calculating the cost of the irrigation. The decision criterion was applied by means of the simulation model to data from three growing seasons. The results were compared to the results as arrived at by irrigating at a 50% available moisture depletion level. It was found that the new criterion (using either method for calculating the cost of irrigation) yielded less total cost plus loss and achieved a better utilization of the available water than did the 50% criterion. While the state of the art does not allow extremely well-based development of the input variables and parameters, available data have shown the concepts of the model to yield adequate results. Much future development of the approach remains, however. (Auth.)
MODEL TYPE: stochastic with empirical functions
COMMENT: The approach used in this work could be of value in assessments of technology impacts; Use of rainfall probability forecasts in modeling pollutant transport and effects, for example.

<12>
Anderson, M.C. 1966. Stand structure and light penetration, II. A theoretical analysis. J. Appl. Ecol. 3:41-54.
ABSTRACT: The constancy of K in the relation of relative light intensity I/I(0) to leaf area index F - I/I(0)=e-KF - is examined for a stand presumed to consist of foliage inclined at a constant angle alpha. When the relative light intensity must be considered over a range of angles of penetration beta, K is not constant unless alpha=0 deg., when K=1, if transmission and reflection are neglected. The departure from linearity increases with increasing values of alpha. The values of K for diffuse and direct light are usually different. Some implications of these findings for prediction of photosynthetic production in plant stands is discussed. The limitations imposed by the theoretical treatment, compared with the structure of actual plant communities, are briefly reviewed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Analysis of Bouguer-Lambert laws. Shows that extinction coefficient is not a constant unless leaves are horizontal. This information can be used in more comprehensive plant growth models and be applied in technology assessment.

<13>
Baker, C.H., and R.D. Horrocks. 1976. CORNMOD, a dynamic simulator of corn production. Agric. Systems 1:57-77.
ABSTRACT: After an extensive literature search, CORNMOD, a comprehensive mathematical model that simulates energy and gas exchange at the plant-air interface, was developed. Predictions of profiles (CO(2) concentration, water vapour, temprature, light, photosynthesis) in the canopy were biologically good enough for many applications, but they revealed the inadequacies in our understanding of the environment within the plant canopy. Also considered were spring and fall tillage and harvest operations. After calculating several spring freeze-thaw periods for the test year, 1969, enough work days were accumulated to complete tillage operations, allowing completion of planting by 12 May. Two 63 hp tractors and associated equipment were used to farm the 81 ha hypothetical farmstead used for test purposes. Without this large investment in equipment, planting date would have been delayed until late June or early July since the spring of 1969 was very wet. The simulated crop was grown under actual 1969 weather conditions. On 4 September the corn crop reached harvest maturity as gauged by a GDD (Growing Degree Day) 'clock'. The simulator predicted a yield of 7368 kg/ha. This was a gross over-prediction of the 4088 kg/ha average reported for 1969 in central Missouri. This over-prediction was accounted for by the ideal conditions given the simulator when actual data were not available. This included leaf angles, CO(2) concentration, and stomatal resistance. Harvesting took 30 days to complete, using one four-row sheller, two trucks, a farm elevator, and 127272 kg of storage capacity. It appeared that the farm dryer was the limiting piece of equipment in the harvesting operation. This crop production simulator forms the basic framework that can eventually analyze more complex systems. However, at this point, the simulator is only in the initial stages of development, and it should be realized that much more extensive development is necessary before the ultimate simulator is achieved. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This is an extensive model dealing with the full range of corn production operations from planting to growth and harvest. The impacts of energy technology on the various stages of corn production could be evaluated through appropriate modification of the model.

<14>
Baker, D.N., and R.E. Meyer. 1966. Influence of stand geometry on light interception and net photosynthesis in cotton. Crop Sci. 6:15-19.
ABSTRACT: The following geometric variables interact to determine the nature of shade pattern in row crops: solar altitude, the angle of the row with respect to the solar azimuth, plant size and planting pattern. Great change during the day was observed in the relative percent interception in all stands when the crop was young. In the early morning and late afternoon NS rows intercepted more light than EW rows. Percent interception began to level off at a leaf area index of about 3 in the conventionally planted cotton. Little or no convergence in the percent interception vs. LAI curves for noon and noon plus or minus 5 hours was noted in the NS-skip cotton up to an LAI of 4 on a per planted acre basis. This indicates that expenditure of net photosynthate in the further elaboration of new leaf tissue would be a good investment as long as the fruit ultimately produced by the plant would have time to mature. Row direction had no significant effect on the total daily net photosynthesis by cotton conventionally planted in 40-inch rows. On a per planted acre basis the NS-skip planted cotton

APPENDIX A
Agricultural Models (continued)

<14> CONT.
consistently outperformed the NS-solid stand and the EW-skip planted stand. In all of the stands the daily time course of net photosynthesis paralleled very closely the course of interception of solar energy. The light data from a flat surface receiver may be adjusted for percent interception by any stand, regardless of geometry, to give an accurate prediction of net photosynthesis. (Auth.)
MODEL TYPE: statistical - regression equation
COMMENT: Early study and empirically tuned for Mississippi conditions. Not useful for assessment since many other mechanistic models are available for light and photosynthesis prediction.

<15>
Balding, P.R., and G.L. Cunningham. 1976. A comparison of heat transfer characteristics of simple and pinnate leaf models. Bot. Gaz. 137(1):65-74.
ABSTRACT: The heat dissipation of simple and pinnate leaf models was compared in terms of boundary layer diffusion resistance to heat flux (Ra) using energy budget equations. The relationships of Ra to length of the leaf along the path of air flow (D), width of the leaf perpendicular to the path of air flow (W), and wind velocity (V) were determined for the single leaf models by placing them in a low velocity, laminar flow wind tunnel and measuring leaf model temperatures as a function of D, W, and V. The relationships of Ra to D, V, angle of interception of air flow (theta) by pinnate leaf models, and distance between leaflets were investigated. Equation coefficients were determined by regression analysis. The results indicate that theta and interleaflet distance are important parameters determining the heat transfer characteristics of pinnate leaves. (Auth.)
MODEL TYPE: mechanistic
COMMENT: A detailed treatment of a specific physical process. Energy technologies could change the leaf characteristics that influence heat exchange, e.g. emissivity.

<16>
Baldwin, J.P. 1975. A quantitative analysis of the factors affecting plant nutrient uptake from some soils. J. Soil Sci. 26:195-206.
ABSTRACT: A model of solute uptake by a growing root system is discussed in relation to the ability of a soil to support the nutritional requirements of plants. It is quantitative, and should apply to the absorption of nitrate, phosphate, and potassium by grasses and arable crops. The principles, if not the detail, are relevant to all soils. The model was tested in an experiment in which the nitrogen and potassium taken up by a rape plant were measured. The results suggest that the model has identified the significant variables in the absorption process. The principal factors affecting the supply of nutrient to a given plant are the total quantity of diffusible nutrient, the rate at which the nutrient can move, and the distance it has to travel to a root surface. The exact relevance of each factor for the different nutrients is readily determined. The diffusion coefficients of potassium and phosphate are often low. Mass flow contributes little to their supply, and an adequate exploitation of the soil reserves depends on a well-developed root system. Nitrate, on the other hand, can usually move easily to roots, either by diffusion or mass flow. The whole rooting volume is depleted fairly quickly, and the amount absorbed depends solely on the quantity present in the rooting volume. These ideas have practical significance. In particular, they suggest that the soil properties which influence root growth may deserve as much attention as soil chemical composition in the drawing up of fertilizer recommendations. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful for modeling chemical uptake from soils. Requires input properties that can be measured or estimated for a given situation.

<17>
Baldwin, J.P., P.H. Nye, and P.B. Tinker. 1973. Uptake of solutes by multiple root systems from soil, III. A model for calculating the solute uptake by a randomly dispersed root system developing in a finite volume of soil. Plant Soil 38:621-635.
ABSTRACT: A procedure is put forward for calculating the plant uptake of solutes supplied by diffusion and mass flow to the randomly dispersed roots of a developing root system. The model was tested as follows: (a) for a constant root density and both transport processes - against a more accurate numerical solution of the same system (b) for an increasing root density and for supply by diffusion only - by electrical simulation using the analog described in Part I. In both cases, results obtained by the two types of calculation were in close agreement. A less accurate method which includes both supply mechanisms and does not require a computer is presented, and compared with an electrical simulation when there is no mass flow. Agreement is within 20%. The model should be useful for predicting plant nutrient uptake from soil, and may be of special interest to modellers of the whole plant system. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Very useful model that can be adapted to estimate pollutant uptake from soil. This model has been incorporated into the solute uptake model described by Luxmoore et al. (1978) Ecol. Modelling 5:137-171.

<18>
Baldwin, J.P., P.B. Tinker, and P.H. Nye. 1972. Uptake of solutes by multiple root systems from soil, II. The theoretical effects of rooting density and pattern on uptake of nutrients from soil. Plant Soil 36:693-708.
ABSTRACT: The analog described in Part I is used to investigate quantitatively the effects of pattern and density on the uptake and uptake rate of nutrients which move to plant roots by diffusion. The uptake by two roots is considered first, to illustrate the competitive effect. The results for multiple root systems are given for a variety of different soil and plant parameters at different times and demonstrate the importance of pattern and density in the uptake of different plant nutrients in both competitive and non-competitive situations. Pattern can decrease the uptake by root systems by at least 75 per cent, depending on the value of the diffusion coefficient, time, and root density. Graphs of two indices of dispersion against uptake are given so that the effect of any pattern can be estimated. A procedure is outlined which enables the uptake after any time by a developing root system to be predicted and compared with a theoretical maximum. If the uptake is known, then the graphs show whether soil or plant parameters are limiting uptake. (Auth.)
MODEL TYPE: electrical analog
COMMENT: Model uses a 2D slab - This model has been superceded by digital simulation codes.

APPENDIX A
Agricultural Models (continued)

<19>
Barr, S. 1971. A modeling study of several aspects of canopy flow. Mon. Weather Rev. 99:485-493.
ABSTRACT: Several aspects of canopy flow are investigated. The problem of steady flow in a horizontally infinite canopy under neutral thermal stratification is treated theoretically. The resulting analytical model is then used as a boundary condition for a nonlinear numerical model designed to study transition regions near the leading and trailing edges of a canopy. This model shows a wave effect downstream from a leading edge observed in the field and laboratory. A tendency for a splitting of the flow near a windward canopy edge is also brought out. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Theoretical analysis that could be used to evaluate possible deposition patterns in foliage.

<20>
Barr, S., and C.W. Kreitzberg. 1975. Horizontal variability and boundary-layer modeling. Bound.-Layer Meterol. 8:163-172.
ABSTRACT: Micrometeorologists have traditionally set aside consideration of horizontal variability and have studied boundary-layer structure with horizontal homogeneity. The numerical forcasting of boundary-layer structures, over normally varying terrain and including normal disturbances such as fronts, requires selection of an 'appropriate' horizontal scale. A simple analysis of steady-state balance between horizontal advection and vertical diffusion provides estimates of the vertical scale (or depth) of surface-induced features. The scale height is a function of the horizontal scale of the variations. Models neglecting important terrain scales of length below approximately 1000 km can predict down to levels of approximately 0.5 to 1 km while those that neglect important terrain scales below approximately 100 km can predict down to approximately 0.2 to 0.6 km. Below these levels, any predicted features will be dominated by the vertical diffusion so that they are solutions of a one-dimensional boundary-value problem. The boundary-induced advection effects dominate free atmosphere advection effects in the lowest few hundred meters as well. This means that if mesoscale advections are resolved and terrain influences are strong, the predictions in the layer approximately 0.2 to 0.8 km can provide mesoscale detail without mesoscale initial conditions above the surface, because the surface forcing will dominate the solution. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Theoretical analysis that can aid in evaluation of terrain effects on turbulent transport in the atmosphere.

<21>
Barron, N.A., M.J. O'Dougherty, and D.S. Boyce. 1973. A simulation model study of plant spacing, establishment and thinning on sugar beet yields. J. Agric. Eng. Res. 18:369-384.
ABSTRACT: A simulation model of sugar beet production covering the stages of seed placement, establishment, thinning, growth and topping was used to evaluate methods of hand thinning, blind thinning, machine selective thinning, and planting to a stand. The results were used to provide information on how initial plant spacing, its standard deviation and plant establishment levels affected the yield of correctly topped beet and of over and undertoppings. The initial spacing and standard deviation requirements for maximum net yield returns varied with method and establishment levels. A standard deviation of 1.0-1.5 in (25-38 mm) was acceptable. In general, the results emphasized the importance of high establishment levels which tended to produce even stands. With good establishment, differences in yield between production methods were small; therefore, the selection of a method is dependent upon its costs and only to some extent on associated yield advantage. (Auth.)
MODEL TYPE: stochastic
COMMENT: Specific to sugar beets - could be used to examine plant density effects, but this is probably only indirectly related to energy technology impacts.

<22>
Barthakur, N. 1975. Use of microwave radiation to study plant-environment interactions. J. Microwave Power 10(4):441-449.
ABSTRACT: A closed-circuit wind tunnel and an external microwave energy source formed the basis of an experimental technique to investigate relationships between climatic parameters and leaf temperatures. The results of these preliminary experiments are compared with theoretical results obtained by solving the energy balance equation for a single leaf. Time-temperature relationship of an attached bean leaf, exposed to microwave radiation, is compared with a mathematical model which is essentially derived from a knowledge of the cooling coefficient and the absorption factor. At high absorbed radiation and in darkness, stomatal opening of a real bean leaf may reduce its temperature between 2 to 5 deg. C. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful in the assessment of microwave effects on leaf temperature.

<23>
Bartos, D.L., and D.A. Jameson. 1974. A dynamic root model. Am. Midl. Nat. 91:499-504.
ABSTRACT: Root fluctuations of a shortgrass ecosystem were determined with 256 cores taken over eight sampling dates during the summer of 1969. Soil cores were taken to a depth of 80 cm to determine the entire profile distribution. Some 60% of the root weight was in the 0- to 10-cm segment, and this increment had significant variations between dates; however, the lower levels remained quite constant. The usual concept of carbohydrate storage in roots, and its subsequent utilization, were not adequate to explain the changes in root weights. Losses of root weights did not coincide with periods of leaf initiation and seed production. A mathematical model which includes concepts of root decomposition and growth was formulated to represent the fluctuations; the model consists of two logistic equations added together. The equation was fitted to the original data via a direct search curve-fitting program. The resultant curve was separated into an increasing curve representing growth and a decreasing curve representing decomposition and respiration losses. According to the model, growth must necessarily begin before, and decomposition must continue after, the time of minimum root weight. Thus, these curves, under several assumptions, all indicate that losses and replacements in roots are greater than those which are represented in the usual root turnover equations. (Auth.)
MODEL TYPE: statistical
COMMENT: Model could form the basis for examining an energy technology impact on grassland ecosystems.

APPENDIX A
Agricultural Models (continued)

<24>
Belot, Y., A. Baille, and J.L. Delmas. 1976. Modele numerique de dispersion des polluants atmospheriques en presence de couverts vegetaux. Atmos. Environ. 10:89-98.
ABSTRACT: A numerical model of atmospheric pollutant dispersion was developed in order to analyse the effects of a plant canopy on air concentrations. The increase in surface roughness is shown to significantly influence the concentration distributions. Moreover the integrated velocities of deposition and the plume depletion are evaluated for particles and SO(2) passing over wooded strips. The model is particularly useful to learn how and where dry deposition occurs in high canopies such as forests. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful for assessment of atmospheric deposition of pollutants in plant communities.

<25>
Blacklow, W.M. 1973. Simulation model to predict germination and emergence of corn (ZEA MAYS L.) in an environment of changing temperature. Crop Sci. 13:604-608.
ABSTRACT: A simulation model was developed based on a system that included the processes of imbibition and elongation of the corn (ZEA MAYS L.) radicle and shoot and the events of germination and emergence. The response of the processes to temperature were described in previous papers. Germination was predicted at a critical level of rehydration of the seed. Subsequent to germination, the radicle and shoot were elongated until the shoot emerged from the soil. The objective of the model was to give a continuous record of the change in state of the system until emergence occurred. The system was updated each hour by simulation based on a knowledge of soil temperature. The model gave good predictions under fluctuating temperatures in controlled environments and in the field. The verified model supported the hypothesis that the germinating seed and its elongating axes respond to prevailing temperatures with no adaptation to preceding conditions, and that the system responds within minutes to changes in temperature. The model was not developed to predict responses to temperature stress (less than 10 C or more than 32 C) or to temperature if other soil factors were limiting. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be used to assess soil temperature impacts of technology on germination and emergence of agricultural crops. Useful in waste heat utilization for example.

<26>
Boast, C.W. 1973. Modeling the movement of chemicals in soils by water. Soil Sci. 115(3):224-230.
ABSTRACT: Models describing the movement of chemicals through soil provide a good example of applying modeling techniques to the soil-water system. Some of the classical macroscopic continuum theories which have been developed are presented here in table form. The emphasis of most studies of the movement of chemicals has been on the influence of steady water flow. Recently approximations have been made to give better solutions for nonsteady flows. In principle, flow models can be used to describe the processes of soil formation; however, the complexity of such mathematical models may be prohibitive. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Gives a comparison of mathematical functions describing chemical movement in soils. Many of the functions are taken from open literature. Useful review paper.

<27>
Booth, R.S., O.W. Burke, and S.V. Kaye. 1971. Dynamics of the forage-cow-milk pathway for transfer of radioactive iodine, strontium, and cesium to man. Proc. of Am. Nucl. Soc. topical meeting on nuclear methods in environmental research, pp. 127-143.
ABSTRACT: A systems analysis model was developed to predict the time-dependent concentration of radiostrontium, radiocesium, and radioiodine in the milk, meat, and soft tissue of cows that forage a pasture contaminated by fallout. The variables in this model are adjustable to a wide variation in weather conditions, ecological conditions, and countermeasures. Simulated concentrations were based on reasonable, conservative parameters derived completely from published measurements. There was continued contamination of the milk and meat several weeks after a short-term deposition on the grass (radioactive cloud above the pasture for 1 hr). However, the concentration in milk was in transient equilibrium with the grass (a 14-day environmental half-time for loss of radioactivity from the grass was specified) within a week after the deposition, and the majority of man's uptake of radioactivity from consumption of milk and meat was accomplished within the first few weeks after deposition. The transfer of radioactivity to man was almost exclusively via the direct grass to cow gut to cow blood (body fluid) to meat and to milk pathway. The predicted equilibrium concentrations indicate the potential uptake by man from a continuous source of radioactivity above the pasture. The influence of environmental conditions and countermeasures was studied. If, for example, the cows were moved from the contaminated pasture 1 day after an impulse source to the grass, the cumulative meat and milk concentration would be only 5% of that obtained when no countermeasures are applied. (Auth.)
MODEL TYPE: systems analysis with empirical transfer coefficients
COMMENT: Useful model for nuclear assessments.

<28>
Brennan, R.D., C.T. de Wit, W.A. Williams, and E.V. Quattrin. 1970. The utility of a digital simulation language for ecological modeling. Oecologia (Berl.) 4:113-132.
ABSTRACT: Dynamic modeling of ecological phenomena has been greatly facilitated by the recent development of continuous system simulator programs. This paper illustrates the application of one of these programs, S/360 Continuous System Modeling Program (S/360 CSMP), to four systems of graduated complexity. The first is a two species system, with one feeding on the other, using differential equations with constant coefficients. The second and third systems involve two competing plant species in which the coefficients of the differential equations are varying with time. The final example considers the management of a postulated buffalo herd in which the dynamics of the herd population and composition by sex and age is combined with various strategies to control its size and to optimize buffalo production. (Auth.)
MODEL TYPE: not a model
COMMENT: Paper discusses CSMP computer language and applications to species competition, plant size distribution and buffalo herd management.

APPENDIX A
Agricultural Models (continued)

<29>
Brook, R.R. 1975. A rationale for determining spacing of levels in numerical models of the atmospheric boundary layer. Bound.-Layer Meterol. 8:447-451.
ABSTRACT: It is suggested that since diffusion is the principal vertical transfer mechanism in the boundary layer, the mixing-length concept can be used to determine the spacing between levels in numerical models. An analysis of the Wangara Experiment boundary-layer data suggests that for that location, a vertical spacing of about 1% of the smallest horizontal scale is appropriate in the spiral layer and that this is constant with height. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Study can aid in boundary layer model applications. Useful in atmospheric transport of pollutants.

<30>
Brown, K.W., and N.J. Rosenberg. 1973. A resistance model to predict evapotranspiration and its application to a sugar beet field. Agron. J. 65:341-347.
ABSTRACT: A method is needed to extrapolate the detailed micrometeorological and lysimetric determinations of evapotranspiration and its dependence on the microclimate and crop factors to fields where such detailed measurements are not made. The dependence of latent heat flux (LE) from a crop on crop resistance (r(c)), air resistance (r(a)), air temperature (T(a)), water vapor pressure (e(a)), and net radiation minus soil heat flux (Rn-S) was evaluated by means of an electrical resistance analogue of the transfer process (referred here as the model) and by means of an energy balance equation. The difficulties inherent in the application of the model to both the single leaf and the crop are discussed. The major difficulty in applying the resistance model to a field crop may be that the sinks and sources of latent and sensible heat flux may not be identical within the crop. Hourly LE predicted by the model and determined by the energy balance generally agreed within 5%. Daily totals of LE, evaluated by the two methods, agreed well on all occasions. Despite the objections to use of this model for a crop, it mimicked the behavior of the irrigated sugar beet crop used here. As more detailed data on experimental fields becomes available, the model may prove useful in extrapolation to extensive vegetated areas. It may also be usefully incorporated into larger models of total hydrologic systems in which evapotranspiration is an important component. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model of evapotranspiration developed from micrometeorological approach. This method requires meteorological inputs and is uncoupled from a mechanistic soil-plant model. Probably has limited use in technology assessment.

<31>
Bunnell, F.L., D.E.N. Tait, P.W. Flanagan, and K. Van Cleve. 1977. Microbial respiration and substrate weight loss, I. A general model of the influences of abiotic variables. Soil Biol. Biochem. 9:33-40.
ABSTRACT: A general model of the influences of abiotic variables on microbial respiration and substrate weight loss is presented. The model, a complex hypothesis relating microbial respiration to temperature, moisture, O(2) and substrate, "explains" 71-96% of the variation in aerobic respiration rates measured from a variety of natural substrates. The model can project seasonal patterns of weight loss and thus permits evaluation of laboratory respirometry against field measures using litter bags. Using data from several countries simulated losses due to microbial respiration are 70-90% of the measured litter bag loss. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model requires four empirical parameters and could be adapted to a range of situations. Evaluaton of physical environment impacts could be made.

<32>
Bunnell, F.L., D.E.N. Tait, and P.W. Flanagan. 1977. Microbial respiration and substrate weight loss, II. A model of the influences of chemical composition. Soil Biol. Biochem. 9:41-47.
ABSTRACT: Three models of the influences of chemical composition on microbial respiration and substrate weight loss are presented. The three approaches represent different means of incorporating influences of temperature and moisture upon chemical-specific respiration rates. Although influences of temperature and moisture dominate microbial respiration patterns, chemical-specific respiration rates do exist with ethanol soluble substrate components respiring about 5 to 10 times as rapidly as non-ethanol soluble components (depending upon temperature). Simulation models are utilized to project and relate the laboratory measures of microbial respiration to field measures of substrate weight loss. Utilizing chemical-specific respiration rates, simulated rates of weight loss from ethanol soluble and non-ethanol soluble substrate components are 48% and 12% per yr. Measured rates are 49% and 11%. After the initial period of relatively high leaching, changes in substrate weight and chemical composition result largely from changing microbial respiration rates which are chemical-specific and independently influenced by temperature and moisture. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Not readily applied to technology assessment without first experimental determination of the impact effect on respiration and decomposition.

<33>
Bunting, E.S. 1972. Ripening in maize: Interrelationships between time, water content and weight of dry material in ripening grain of a flint x dent hybrid (Inra 200). J. Agric. Sci. Camb. 79:225-233.
ABSTRACT: Results are reported of ripening studies with maize (var. Inra 200) at Oxford, 1967-69. Sowings were made in late April or early in May, and crops grown at a standard density of 7.2 plants/m**2. Areas were provided with cloche protection, for a 4- to 5-week period from time of sowing, to produce material for studies of the effects of flowering time on ripening patterns. From plants of known flowering date, collections of 30-40 ears were taken at intervals from 30 until 100+ days after silking. Information is presented on water content, grain dry weight and number of grains/ear at the various times of harvest. Asymptotic, polynomial and inverse-polynomial regression models have been fitted to the data to elucidate the interrelationships between time (measured from date of silking), grain water content and grain dry weight. In plants flowering in mid-July grain continued to increase in dry weight until water content was reduced to 35%, whereas in plants flowering early in August maximum dry weight was attained at a water content of around

APPENDIX A
Agricultural Models (continued)

<33> CONT.
40%. Maximum dry weight of grain was approximately 10% higher in the earlier flowering plants; the corollary is that in the marginal areas of maize grain production in England maturity in such varieties as Inra 200 is often imposed by the environment with a consequent loss in potential yield. In the early flowering plants, the time taken from silking to reach the harvestable stage of 40% grain water content was 69 d in 1967, 79 d in 1968 and 64 d in 1969. Rate of water loss from the grain during ripening was closely related to prevailing air temperatures. In the later flowering plants, differing by an average of 11 d in time of silking, 8 days longer was required for grain to be reduced to 40% water content, giving an average difference of 19 days in permissible dates of harvest. The results suggest that, in varieties of similar ripening pattern to Inra 200, an advance of about 7 days in flowering time is required to establish the maize grain crop beyond its present confines in southeast England. (Auth.)
MODEL TYPE: statistical
COMMENT: Regression equations are developed for English conditions. Might be useful to compare with any impact that changes cereal ripening patterns.

<34>
Bureau of Reclamation 1977. Prediction of mineral quality of irrigation return flow. EPA-600/2-77-179a, USEPA, Ada, OK.
ABSTRACT: This volume of the report outlines the purpose and scope of the return flow research and specifically explains the capabilities of the conjunctive use model for predicting the mineral quality of irrigation return flow. The purpose of the research was to develop a conjunctive use model which would (1) predict the salinity contribution from new irrigation projects and (2) predict the change in return flow salinity that would result from operational changes on existing projects. The model developed and described herein describes the chemical quality in terms of eight ionic constituents and total dissolved solids. A nodal concept has been used to facilitate subdividing the project area along physical or hydrologic boundaries as desired. The study may be limited to 1 or as many as 20 nodes. A description of the Vernal Field Study which describes the physical setting for the model testing is included. A narrative describing the problems encountered with the original data is included. A data collection program was initiated to fill the gaps. The model satisfactorily simulated the new 2-year data base. Tables and figures showing the computed-observed comparisons from the verification are included. Results of model operations for the Cedar Bluff and Grand Valley areas are also described. It is concluded that the model can satisfactorily be used to simulate irrigation return flows if sufficient data are available, especially groundwater hydrology and chemistry. This report was submitted in fulfillment of Project EPA-IAG-D4-0371 by the U.S. Bureau of Reclamation, Engineering and Research Center, under the sponsorship of the Environmental Protection Agency. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This five volume series is an extensive model development and testing study concerned with water quality. It has considerable utility in evaluation of some energy technology impacts.

<35>
Byrne, G.P. 1975. A simple method of calendar conversion in computer applications - Discussion. Agric. Meteorol. 15:419.
ABSTRACT: A method of data conversion for use in the computer handling of climatological and similar data is described. The procedure incorporates a test for occurrence of leap years and also a test for automatic conversion in either direction. (Auth.)
MODEL TYPE: algebraic
COMMENT: Useful algorithm in model applications requiring date conversions.

<36>
Caassen, N., and S.A. Barber. 1976. Simulation model for nutrient uptake from soil by a growing plant root system. Agron. J. 68:961-964.
ABSTRACT: Mathematical models of nutrient uptake by plants are useful for investigating the effect of various soil and plant factors on nutrient flux to plant roots. The objective of this research was to develop a model based on theoretical considerations of the processes of nutrient uptake by plant roots growing in soil and then to test the model experimentally. The soil and plant factors used in the model were to be measured independent of final nutrient uptake. The model for flux by mass flow and diffusion to the root was patterned after that of Nye and Marriott. The absorption kinetics of the root were assumed to follow Michaelis-Menten kinetics. The Nye-Marriott model gives the nutrient concentration at the root with time. From this accumulated uptake per cm**2 of root surface with time was calculated. Rate of root growth was assumed exponential for the growth of the young plant. Uptake per cm**2 of root with time was combined mathematically with rate of root growth to get total uptake with time by the plant. The present program assumes root hairs do not affect uptake and that roots do not compete for nutrients. A computer program was written for solution of the mathematical model. The factors required in the model from the soil are: effective average diffusion coefficient, initial nutrient concentration in solution, and buffering capacity. For the plant they are: the relation between nutrient concentration in solution and net influx into the root, water influx, root radius, initial root length, and rate of root growth. The model was tested for measuring K uptake by corn (ZEA MAYS L.) from eight different soil-K combinations. The corn was grown in a growth chamber and K uptake was measured for the period of plant growth from 4 to 10 and 13 days. The calculated uptake, y, was correlated with observed uptake, x, by the equation y=0.155+1.566x (R**2=0.87) where y and x are micromoles of K/plant. Calculated uptake was overestimated by about 50%, possibly because competition occurred between roots for soil K and K was not absorbed by the root as fast at night as in the day. The model should be useful for investigating the principles of nutrient absorption by plant roots from soil which can be used for developing more efficient systems of fertilizer application. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Research model that could be adapted to technology assessment.

<37>
Campbell, M.D., G.S. Campbell, R. Kunkel, and R.I. Papendick. 1976. A model describing soil-plant-water relations for potatoes. Amer. Potato J. 53:431-441.
ABSTRACT: A simple steady state model is derived which describes the diurnal water potential fluctuations in leaves and tubers of potatoes. The magnitude of these

APPENDIX A
Agricultural Models (continued)

<37> CONT.
fluctuations is shown to depend on transpiration rate, hydraulic properties of the soil, rooting depth and density, resistance to flow of water within the plant, and the leaf water potential at which stomatal closure occurs. Model predictions agree quite well with measurements made in the field and in the growth chamber. The model is used to predict the lower limit of readily available moisture for potatoes and shows the important environmental and plant factors. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful model for assessment of energy technology effects on water relations of potatoes.

<38>
Carbon, B.A., and K.A. Galbraith. 1975. Simulation of the water balance for plants growing on coarse-textured soils. Aust. J. Soil Res. 13:21-31.
ABSTRACT: A computer simulation model of the water balance for plants growing on coarse soils was developed and tested against field measurements. The inputs for this model are measurable physical parameters. From the close agreement between simulated and observed results, it is suggested that evaporation, soil water storage and deep drainage may be satisfactorily predicted. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Empirical model tuned to western Australian conditions. Has the advantage of requiring relatively few input data. Probably not readily applicable to technology assessment.

<39>
Charles-Edwards, D.A., and J.H.M. Thornley. 1973. Light interception by an isolated plant - A simple model. Ann. Bot. 37:919-928.
ABSTRACT: A simple model for light interception by an isolated plant is proposed. The model assumes that the leaves are uniformly distributed over a region of space bounded by an ellipsoid and a plane, and that light traversing this region is attenuated according to Beer's law. It is shown how the model can be extended to examine a closed row of plants, or a closed array of plants. Simulated light profiles have been calculated for single plants with different shapes, and an isolated row of plants, under uniform and standard overcast skies. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Probably not useful in assessment. The method could be incorporated into more comprehensive models of plant function.

<40>
Chen, C.S., and J.T. Clayton. 1971. The effect of temperature on sorption isotherms of biological materials. Trans. of the ASAE 14:927-929.
ABSTRACT: This paper presents an analysis of sorption isotherms pertaining to hygroscopic materials. Two two-parameter and one three-parameter empirical sorption equations were investigated for a number of grains. At a given temperature, Chen's equation exhibited the best fit of the three equations. A new four-parameter equation relating equilibrium moisture content, air relative humidity, and equilibrium temperature was developed on the basis of the simplified Chen equation. Applications to published data on a number of materials indicate that the goodness of fit of the predicted values is better than that of Day and Nelson's modified Henderson four-parameter equation. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful model in the application of waste heat in drying biological materials.

<41>
Chen, L.H., B.K. Huang, and W.E. Splinter. 1969. Developing a physical-chemical model for a plant growth system. Trans. of the ASAE 12:698-702.
ABSTRACT: Growth was considered as a function of two major energy conversion processes - photosynthesis and respiration. A functional relationship between photosynthesis, respiration, and growth was developed. Under present studies, the information available for complete evaluation of model constants is not sufficient. A thorough study on the following subjects will make this model more satisfactory: (1) Temperature effect on rate of photosynthesis (2) Interactions between light intensity and temperature effects on rate of respiration (3) Temperature effect on rate of translocation. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model is based on a lumped view of plant growth. Could be useful for assessment; however, other plant growth models may be more suitable.

<42>
Childs, S.W., and R.J. Hanks. 1975. Model of soil salinity effects on crop growth. Soil Sci. Soc. Am. Proc. 39:617-622.
ABSTRACT: The model considers properties of the soil, water, plant, and atmospheric system to predict relative crop yield. Crop yield predictions assume a direct relation between dry matter production and transpiration. The only salinity effects considered are osmotic potential. The influence of initial soil salinity on crop growth depended upon the crop type and irrigation management. Predictions made of salt buildup over several years show that some water management systems would produce high yields for several years before salt buildup would decrease yields. Predictions show that the influence of irrigation system uniformity on salinity buildup and yield reduction is very important. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could evaluate the use of blowdown water for crop irrigation.

<43>
Chung, C.W., J. Duffy, and H.A. Hirsch. 1974. Systems manual for FIELD, a program for the simulation of nitrogen flow in a corn belt field. CBNS Report No. 7402, Washington Univ., St. Louis, MO.
MODEL TYPE: parametric
COMMENT: Very useful model that could be adapted to evaluate technology impacts in similar situations to the corn belt field used in the model development and application.

<44>
Cionco, R.M. 1965. A mathematical model for air flow in a vegetative canopy. J. Appl. Meteorol. 4:517-522.
ABSTRACT: The objectives of this study are to investigate the turbulent transfer of momentum within a vegetative canopy and also to develop a mathematical model which expresses the aerodynamic roughness effects of the surface boundary in terms of the height, density, and drag characteristics of a vegatative canopy. To date three mathematical models have been formulated. The present model reflects both the theoretical and empirical aspects of the two

APPENDIX A
Agricultural Models (continued)

<44> CONT.
previous models and other available canopy observations. Computed mixing length solutions showed that the mixing length, l, was nearly constant throughout most of the canopy's vertical extent and also that l increased linearly with height above the canopy. The computed canopy wind profile solutions verified that the mixing length is nearly constant with height within a mature corn plant canopy and that the simulated canopy wind profiles agreed quite well with the observed canopy wind data of a cornfield. An independent check on the model was performed using wind tunnel data for an artificial canopy; once again the simulated canopy wind profiles were in good agreement with the observed data. Example profiles of the mixing length and the canopy wind profiles are presented along with simple scatter diagrams to summarize the analysis of the model data. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model is for basic research of air flow through vegetation and provides insights into factors influencing microclimate of vegetation. May have some use in assessment.

<45>
Coligado, M.C., and D.M. Brown. 1975. A bio-photo-thermal model to predict tassel-initiation time in corn (ZEA MAYS L.). Agric. Meteorol. 15:11-31.
ABSTRACT: A bio-photo-thermal model to predict tassel-initiation time in corn was formulted and tested using data obtained from controlled-environment studies and from field planting-date experiments with and without light extension. This model incorporates a genetic factor, mean daily temperature, photoperiod, temperature range and a development potential factor as predictor variables. The model uses the concept of delay from the shortest time to tassel initiation caused by sub-optimal predictor variables determined on a daily basis. The shortest time was obtained with a mean daily temperature of 25 deg. C, photoperiod of 10 h and a temperature range of 0 deg. C (constant day and night temperatures). Each of these conditions was considered to be optimum. With the incorporation of the development potential factor, the predictions from the model were within one day of the observed number of days to tassel initiation in the field. There was an average deviation of 0.46 day. The corn-heat-unit, the growing-degree-day and the U.S. Weather Bureau thermal unit models were tested as predictors of tassel-initiation time in corn using the same field data. Modifications to these models with the inclusion of photoperiod, a development potential factor and a combination of both were also tested. The predictions from the bio-photo-thermal model were found to be superior to the predictions made from any one of the thermal unit models and their modifications. Among the unmodified thermal unit models tested, the corn-heat-unit model gave predictions with the least average deviation, followed by the growing-degree-day and lastly, by the U.S. Weather Bureau model. The introduction of the development potential factor, photoperiod factor or both improved the prediction of the corn-heat-unit and the U.S. Weather Bureau models. Improvement in the growing-degree-day was attained only with the introduction of the photoperiod factor. This study has demonstrated the possibility of prediction of tassel-initiation time in corn within a reasonable practical level of accuracy by the use of the bio-photo-thermal model. (Auth.)
MODEL TYPE: regression equations
COMMENT: Could be used to evaluate some technology impacts.

<46>
Collis-George, N., and M.D. Melville. 1975. Water absorption by swelling seeds, I. Constant surface boundary condition. Aust. J. Soil Res. 13:141-158.
ABSTRACT: Recent analyses of water absorption by seeds have used a non-swelling model with constant diffusivity and constant surface concentration boundary condition. A physically realistic modification of such analyses is developed, where the spherical seed has the properties of normal swelling, moisture content dependent diffusively, and a moisture characteristic which is described by the double layer theory relevant to colloids under mechanical restraint. Analysis of this model by a finite difference approximation produces a relationship between linearized moisture content and dimensionless time which is appropriate to all spherical swelling materials. A good match was obtained between this relationship and experimental absorption data for wheat seed. The relationship given graphically in dimensionless form is applicable to any swelling system, e.g. soil aggregates, which satisfy normal swelling and constrained double layer boundary conditions. The analysis gave values for the diffusivity of the seed similar to, but larger than, those calculated from non-swelling models. These are much smaller than most values of diffusivity of soils in the available water range. The magnitude of the maximum rate at which a seed can absorb water relative to that which the soil can supply, predicts that for seeds embedded in most soils, the constant surface concentration boundary condition used by most authors is inappropriate. In terms of the swelling behaviour of most soils, the swelling model, unlike the non-swelling model, predicts that imbibing seed embedded in soil will be subject to a mechanical constraint. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model is oriented more to basic research than assessment applications.

<47>
Connor, D.J., L.F. Brown, and M.J. Trlica. 1974. Plant cover, light interception, and photosynthesis of shortgrass prairie - A functional model. Photosynthetica 8(1):18-27.
ABSTRACT: A functional model to describe the relationship between community photosynthesis, leaf area index, irradiance, ambient temperature, and soil water potential is proposed and tested with field data collected on blue grama (BOUTELOUA GRACILIS Lag.), the dominant species of shortgrass prairie. It involves an assessment of radiation interception, of photosynthetic response under optimum conditions, and the introduction of proportionality factors to account for the effects of non-optimum conditions of ambient temperature and soil water stress. The predictive performance of the model is compared with that of several statistical models derived from the same experimental data. The multiple correlation coefficient of 0.76 for the functional model is highly significant (P less than 0.01). (Auth.)
MODEL TYPE: mechanistic
COMMENT: This grassland model could be adapted to evaluate environmental impacts of energy technologies.

<48>
Connor, D.J., and O. Cartledge. 1970. Observed and calculated photosynthetic rates of

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<48> CONT.
CHLORIS GAYANA communities. J. Appl. Ecol. 7:353-362.
ABSTRACT: Photosynthetic rates of CHLORIS GAYANA (Rhodes grass) communities were calculated using mathematical models. The models relate the photosynthetic contribution of the leaves to direct and diffuse radiation and to the distribution pattern of the foliage, by means of photosynthetic response functions. The calculations are shown to agree with photosynthetic rates measured gasometrically with a portable field chamber. Communities with a leaf area index greater than 2.5 can be adequately represented by a single, continuous, horizontal foliage layer. In a general model, appropriate to all communities and capable of accepting multiple photosynthetic response data, a consideration of alternative strategies indicates that leaf angle need only be specified in terms of the mean angle per leaf layer, although there is a suggestion in some of the data, that the incorporation of leaf angle distribution improves the accuracy of the mathematical approach in some situations. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be helpful in photosynthesis assessments.

<49>
Curry, R.B. 1971. Dynamic simulation of plant growth - Part I. Development of a model. Am. Soc. Agric. Eng. Trans. 14(5):946-959.
MODEL TYPE: mechanistic
COMMENT: Physiological research model that is not directly applicable to assessment. The model has been further developed since this report.

<50>
Daynard, T.B. 1971. Characterization of corn (ZEA MAYS L.) canopies from measurements of individual plants. Agron. J. 63:133-135.
ABSTRACT: Because of their distichous growth habit, the foliage structure of individual corn (ZEA MAYS L.) plants can be diagrammed by placing them against a flat surface and outlining leaf positions on the surface by means of a marking pencil. A method is described whereby measurements made in such a manner are used by a computer program to predict the canopy characteristics of identical corn plants in various planting arrangements. The program output includes quantitative two-dimensional descriptions of plants placed in different row-width planting patterns, plus a measure of the leaf area and leaf angle characteristics of the various vertical layers of such canopies. Typical results with two common hybrids are presented. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Not directly useful but could be incorporated intc more comprehensive plant modeling studies of canopy processes.

<51>
de Jager, J.M., and J.B. Mallett. 1972. Effect of moisture stress upon maize production and its economic significance. S. Afr. J. Sci. 68:182-186.
ABSTRACT: A mathematical model is established for determining the time of occurrence and number of days of moisture stress experienced by a maize crop during a growth season. As input data the model requires values of daily evaporation and rainfall and is applicable to Doveton series soils 1.2 m in depth. Field capacity of each of four soil layers must be known and the manipulations account for variations in root distribution with crop development. The model has been computerized and applied to data from three farming regions in Natal. Expected average gross margins for each area were calculated. Utilizing a figure describing the decrease in final yield per unit stress day experienced, it was possible to determine the probability of occurrence of maize yields between selected limits. (Auth.)
MODEL TYPE: parametric
COMMENT: Model requires empirical data for study area. It is relatively simple in concept and could have wide application in assessment.

<52>
Duncan, W.G. 1971. Leaf angles, leaf area, and canopy photosynthesis. Crop Sci. 11:482-485.
ABSTRACT: For leaf area indices (LAI) of less than approximately 3.0, differences in leaf angle are predicted by computer simulation to have only small effects on canopy photosynthetic rates. For higher LAI values, layers of vertical and horizontal leaves can be arranged to give both the highest and lowest possible rates of canopy photosynthesis for the conditions assumed. These arrangements of leaf layers and angles are not much affected by leaf type or latitude within usual limits. The ratio of highest to lowest photosynthetic rate varied from 1.14 at LAI 3.0 to 2.0 at LAI 10.0. Calculations with one set of corn (ZEA MAYS L.) descriptions indicate that canopy photosynthetic rates may range from 92% of theoretical maximum at LAI 3.0 to 76% at LAI 7.0.
MODEL TYPE: mechanistic
COMMENT: Model could evaluate energy technology effects on leaf area and leaf angle in terms of plant photosynthesis changes.

<53>
Duncan, W.G., R.S. Loomis, W.A. Williams, and R. Hanau. 1967. A model for simulating photosynthesis in plant communities. Hilgardia 38:181-205.
MODEL TYPE: mechanistic
COMMENT: An early mechanistic plant model that has been used as the basis of more detailed plant models. Not recommended for assessment in view of more recent model availability.

<54>
Dunham, R.J., and P.H. Nye. 1974. The influence of soil water content on the uptake of ions by roots. J. Appl. Ecol. 11:581-595.
ABSTRACT: Uptake and concentration gradients of chloride in soil in the vicinity of a plane of onion roots were measured at a range of soil water contents. Uptake was greater at higher water contents, and the zones of depletion in the soil spread further from the roots. A relatively simple theoretical model of ion transport to roots accounted for the trends among the measured concentration gradients - including an accumulation of chloride at the root surface in one case where transpiration was comparatively high. A more detailed model which took account of the water content changes observed during the uptake period satisfactorily reproduced the general shape of the measured gradients, but tended to underestimate the spread of the depletion zones. A possible reason for this was that hydrodynamic dispersion by the water flux to the roots increased the effective diffusion coefficient of chloride and thus increased the spread. Although, ideally, the root absorbing power used in the model should have been continuously adjusted to take into account chloride concentration and matric potential changes at the root surface, the values which gave the concentration gradients that fitted most closely to the measured

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<54> CONT.
gradients, agreed well with the root absorbing powers calculated from the measured uptake. At higher soil water contents these values of the root absorbing power also agreed with those obtained for onion seedlings growing in stirred nutrient solution. At lower soil water contents, however, when the matric potential at the root surface fell to about -25 bar, the root absorbing power was lower (approx. x0.2) than that for nutrient solution. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model considers one dimension uptake and is less useful than the work of Baldwin, Nye and Tinker 1973 which considers cylindrical root sinks for solutes. This paper contains useful data for onion.

<55>
Dutt, G.R., M.J. Shaffer, and W.J. Moore. 1972. Computer simulation model of dynamic bio-physiochemical processes in soils. Technical Bulletin 196, University of Arizona, Tucson.
ABSTRACT: A digital computer model was developed to simulate the effect of certain environmental and managerial factors on soil-water-plant systems. From an initial state and time sequential input variables, the model simulated the non-steady state chemical, physical, and biological changes occurring in the unsaturated soil matrix and percolating water. To demonstrate the usefulness of the model, a hypothetical problem of environmental concern was simulated. Predictions for a period of thirteen years were made to assess the effect of three levels of N fertilization on the N content of water reaching the water table. All other factors were held constant. In the problem considered, only the highest level of fertilization substantially increased the N content of the effluent from the soil. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model contains considerable detail and is calibrated for soils of western USA which are not strongly acid (pH > 6.5). This work has considerable use for assessment purposes.

<56>
Eagleman, J.R. 1971. An experimentally derived model for actual evapotranspiration. Agric. Meteorol. 8(4-5):385-394.
ABSTRACT: Experimental data from several different climatic regions were used to develop a statistical model for actual water loss rates from land surfaces. The actual evapotranspiration rate was considered to be influenced by the amount of available water in the soil and by meteorological and plant conditions which determine the potential evapotranspiration rate. Experimental measurements of these three variables from various environmental conditions were combined into a single model expressing the composite relationship. Actual evapotranspiration rates were calculated from this relationship using the variables soil moisture and potential evapotranspiration. Initial testing showed that the model gave satisfactory results when used for estimating moisture changes in the soil. (Auth.)
MODEL TYPE: statistical
COMMENT: Model could be used for the conditions tested. Considerable uncertainty exists for other applications.

<57>
Eckardt, F.E., G. Heim, M. Methy, M. Saugier, and B.R. Sauvezon. 1971. Functioning of an ecosystem on the level of primary production measurements carried out on a crop of HELIANTHUS ANNUS. Oecologia. Plantarum 6(1):51-100.
ABSTRACT: The functioning of an ecosystem - a HELIANTHUS ANNUS crop - is studied from the point of view of: (1) interception of radiant energy by the plant cover, (2) energy conversion in photosynthesis, (3) use of products of photosynthesis in building up of biomass with special reference to radiant energy intercepting organs and (4) respiration involved in maintenance and growth emphasis being laid on effects of water stress on these system characteristics considered separately and as a whole. Four methods have been used: the energy balance method, the cuvette method with automatic control of the CO(2) concentration, temperature and humidity of the air, growth analysis and mathematical modeling. Good agreement of results is obtained when applying these methods to the determination of carbon uptake by the ecosystem from the lower atmosphere during the day. Variation about their normal values of various parameters related to structure and functioning of the plant cover in simulation experiments with the model made it possible to evaluate their role in net production. During the vegetative phase and until the end of flowering, dry matter production and fixation of chemical energy are proportional to the fixation of carbon; from then on, dry matter production is reduced and energy fixation increased in relation to carbon fixation. Photosynthesis expressed as a function of leaf surface area is not affected by water stress and no afternoon depression is observed, the plant reacting to drought by restricting leaf surface development. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Comprehensive study using the de Wit (1965) model for photosynthesis of leaf canopies.

<58>
Edwards, D.G., and C.J. Asher. 1974. The significance of solution flow rate in flowing culture experiments. Plant Soil 41:161-175.
ABSTRACT: Solution flow rate is an important factor to be considered when designing or operating flowing culture equipment. A theoretical model is developed showing that the actual flow rate required for a particular experiment will depend upon many factors, important among which are the nature and concentration of the ion under consideration, the quantity of roots per pot, and the efficiency of these roots in absorbing the test ion under the conditions of the experiment. The results of experiments conducted at low concentrations of ammonium and nitrate nitrogen clearly demonstrate that flow rates of the order of 1 litre per pot per minute or greater may be required to prevent excessive depletion of the nutrient solution. At lower flow rates, solution depletion resulted in substantial reductions in growth and nitrogen uptake. Quantities of nutrient solution required for experiments at very high flow rates can be reduced to practical levels by the use of recirculating flowing culture systems, even in installations containing large numbers of pots. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model applies to a flow culture regime that could be used in specialized assessment studies.

<59>
Elfving, D.C., M.R. Kaufmann, and A.E. Hall. 1972. Interpreting leaf water potential measurements with a model of the

APPENDIX A
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<59> CONT.
soil-plant-atmosphere continuum. Physiol. Plant. 27:161-168.
ABSTRACT: A water flux model, which assumes that the dynamic functioning of the soil-plant-atmosphere continuum may be described by a series of steady states, was examined as a means for interpreting leaf water potential measurements in 'Valencia' orange trees (CITRUS SINENSIS (L.) Osbeck). According to the model, leaf water potential should be related to transpirational flux, which in this experiment was estimated by the ratio of vapor pressure deficit of the atmosphere to leaf diffusion resistance (VPD/r(leaf)). Leaf water potentials decreased in a specific relationship with increasing values of VPD/r(leaf) provided that soil water was adequate and soil temperature was not too low, but regardless of season of the year or climatic or edaphic differences among 3 field locations. When soil water tensions exceeded 0.3 bar or when soil temperatures were lower than 15 deg. C, deviations from the model occurred in the form of more negative leaf water potentials than predicted by VPD/r(leaf). The model predicts from simple measurements made on intact plants that these differences were due to the modification of flow resistances by cool temperatures and the modification of both resistances and the potential of water at the source in the case of soil water depletion. The model may be a useful tool for interpreting plant water potential data under contrasting environmental conditions. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used to examine plant water potential response to changes in environmental conditions induced by an energy technology.

<60>
Enfield, C.G., and B.E. Bledsoe. 1975. Kinetic model for orthophosphate reactions in mineral soils. EPA 660/2-75-022.
ABSTRACT: This study showed the reaction of phosphorus with mineral soils is not instantaneous. Thus, using equilibrium isotherms will yield erroneous conclusions as to the ability of a soil to sorb phosphorus. The suitability of several kinetic models describing phosphorus reactions in mineral soils was evaluated. Of the models evaluated, a diffusion-limited process paralleling heat flow theory for the storage of heat in spheres best describes the experimental data. Combining the kinetic model with a mass balance equation, one should be able to accurately predict the miscible displacement of phosphorus through mineral soils. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used in evaluation of wastewater disposal on land.

<61>
Enfield, C.G., and D.C. Shew. 1975. Comparison of two predictive nonequilibrium one-dimensional models for phosphorus sorption and movement through homogeneous soils. J. Environ. Qual. 4:198-202.
ABSTRACT: Two models were tested for their ability to predict phosphorus breakthrough curves. The basic difference between the two models is the method of describing the kinetics of sorption. It was found, when comparing theoretically predicted breakthrough curves with experimental breakthrough curves, that the model using a kinetic equation with power coefficients produced a better fit to the experimental data than a first order rate equation. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful results showing that a kinetic phosphorus sorption model should be included in soil chemical transport simulators. The sorption model requires empirical constants. This model could be applied in some technology assessments.

<62>
Fawcett, R.G., and O.G. Carter. 1973. Utility of a simple soil water budget model in agronomic research, I. Effects of plant density, time-of-sowing and fallow water on available soil water under spring wheat. Aust. J. Exptl. Agric. Anim. Husb. 13:714-717.
ABSTRACT: A simple soil water budget model was used to estimate weekly changes in available soil water as affected by plant density, time of sowing and level of available fallow water for spring wheat cultivars grown on a black earth in northern New South Wales. Estimated values of available water were mostly within plus or minus 10 mm of observed values (ranging from 50-270 mm) obtained at four intervals during the growing season. The results are discussed in relation to both the interpretation of agronomic field experiments and use of the model in regions where conserved fallow water contributes significantly to cereal production. (Auth.)
MODEL TYPE: statistical
COMMENT: Model tuned to Australian conditions. Probably not suitable for assessment under USA conditions.

<63>
Fawcett, R.G., and O.G. Carter. 1974. Utility of a simple soil water budget model in agronomic research, III. Estimation of the potential evapotranspiration function. Aust. J. Exptl. Agric. Anim. Husb. 14:684-688.
ABSTRACT: It has been shown that a regression equation relating the cumulative potential transpiration function (T/Eo) with the yield of tops, week of sowing and available fallow moisture, together with a simple budget model, can be used to estimate weekly changes in available soil water under a wheat crop. It is concluded from the data that use of the equation and budget model should be most suited to situations where plant densities are about 60 plants per m**2 and the available fallow water is about 150 mm or less. (Auth.)
MODEL TYPE: statistical
COMMENT: Model is tuned to Australian conditions. Probably not suitable for USA but the approach could be applied in the US.

<64>
Feddes, R.A., E. Bresler, and S.P. Neuman. 1974. Field test of a modified numerical model for water uptake by root systems. Water Resour. Res. 10:1199-1206.
ABSTRACT: Data obtained from careful water balance studies on water uptake by the roots of red cabbage are compared with results obtained from a modified numerical model of Nimah and Hanks. In the modified model the air dry moisture content at the soil surface may vary with time depending on meteorological conditions. The maximum possible rate of evapotranspiration is calculated by considering both meteorological conditions and crop properties. Data are quoted to suggest that the coefficient of the root sink may sometimes vary exponentially with depth. A period of 7 weeks was simulated, and the calculated weekly moisture profiles did not agree completely with those measured in the field. On the other hand, the calculated cumulative rates of

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<64> CONT.
evaporation and transpiration were in excellent agreement with the field data. When the original model was used without the suggested modifications, the agreement of these rates with the field data was not as good, an indication that some of these modifications actually improve the predictive capabilities of the model. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This is a research model that could be adapted to evaluate effects of an energy technology on field water dynamics.

<65>
Perry, D.M., and R.A. Olsen. 1975. Orientation of clay particles as it relates to crusting of soil. Soil Sci. 120:367-375.
ABSTRACT: A simple model for a soil crust was formulated and experimentally tested. It is based upon the parallel orientation and close packing of clay particles perhaps like that in shale. The physical and chemical factors which disrupt the ordered arrangement of the plate-shaped particles were noted to be those which induce aggregate formation and which result in good soil structure. The factors which induce greater orientation and packing were noted to be those which induce crust formation and poor soil structure. The resultant deleterious effects upon seedling germination, moisture penetration and runoff, aeration, and penetrability to roots are well known. Experimental attempts were made to test the validity of the proposed model. In each instance, the data either provided support for the model or else could be reasonably reconciled with the model. The model appears to provide a reasonable basis for explaining cultural practices which are known to influence soil structure in either beneficial or deleterious ways. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used empirically to evaluate crusting effects of energy technology effluents.

<66>
Pery, R.L., and J. Janick. 1971. Response of corn (ZEA MAYS L.) to population pressure. Crop Sci. 11:220-224.
ABSTRACT: The response of field and sweet corn (ZEA MAYS L.) to population pressure was investigated using square and row spacing arrangements with population levels ranging from 2,375 to 151,957 plants per ha (961 to 61,496 plants per acre). Grain yield per unit area peaked at a finite population level, while total top yield appeared to be asymptotically related to plant population. Of the various models tested only the "modified reciprocal" adequately described the response of both grain and total top yield per plant to changes in plant density. One empirical constant can be estimated from yield changes with plant density. Another constant may be useful both as a selection criterion in breeding for increased yield and as a parameter in population and plant distribution studies. (Auth.)
MODEL TYPE: regression equation
COMMENT: Empirical function fitted to field experimental data. Might be useful in a crop population model that simulates environmental effects on plant density.

<67>
Pick, C.W., W.A. Williams, and R.S. Loomis. 1973. Computer simulation of dry matter distribution during sugar beet growth. Crop Sci. 13:413-417.
ABSTRACT: Seasonal growth curves of sugar beet (BETA VULGARIS L.) were simulated by a CSMP computer model called SUBGRO. The hypothesis on which the simulations were based was a hierarchy of priorities for photosynthate partitioning. In order of importance, these priorities were as follows: respiration, top growth, fibrous root growth, and storage root growth including sucrose accumulation. Simulations agreed well with field observations when these priorities were used. Simulated growth did not match field observations if the sequence was changed. The rate of use by each sink was further regulated by its growth potential and by its environment. Functional leaf and fibrous-root surfaces played key roles in regulating the growth rates through a quantitatively expressed set of partitioning functions. To test the partitioning hypothesis, simulated recovery patterns from partial defoliation or root pruning were compared to experimental observations. Simulated recovery was similar to that of real plants. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model used to test hypothesis about plant growth. The tested model could form the basis for evaluation of pollutant or irrigation effects on sugar beet growth.

<68>
Piscus, E.L. 1975. The interaction between osmotic- and pressure-induced water flow in plant roots. Plant Physiol. 55:917-922.
ABSTRACT: This paper presents a general model for coupled solute and water flow through plant roots based on the thermodynamics of irreversible processes. The model explains in a straightforward manner such experimentally observed phenomena as changes in root resistance, increased solute flux, and apparent negative resistance, which have been reported for root systems under the influence of a hydrostatic pressure gradient. These apparent anomalies are explained on the basis of the interaction between the osmotic and hydrostatic driving forces and the well known "sweeping away" of dilution effect. We show that with a constant hydraulic conductivity the only features necessary to explain these phenomena are some type of membrane or membranelike structure and a mechanism for actively accumulating solutes. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model is used for theoretical analysis and is not readily adapted to technology assessment.

<69>
Pitzpatrick, E.A., and H.A. Nix. 1969. A model for simulating soil water regime in alternating fallow-crop systems. Agric. Meteorol. 6:303-319.
ABSTRACT: In developing a methodology for quantitative agroclimatic assessment within a sub-humid to semi-arid region in central Queensland with sparse meteorological and agronomic data, a set of simple working functions depicting evaporative losses of an alternating fallow-crop system was derived. Given weekly rainfall and estimates of potential evaporation as basic inputs, these functions are used to generate a continuous simulation of week-to-week changes in soil water. Despite data inadequacies, a close simulation of temporal changes in soil water regime was obtained using distinctive functions for fallowed and cropped intervals, and by making evapotranspiration rates dependent upon stage of crop development and status of available soil water obtained as a feedback from the model. The levels of stepped functions used in the model to express evaporative loss during fallowed and

APPENDIX A
Agricultural Models (continued)

<69> CONT.
cropped intervals were fitted in part by applying previous functions presented by Slatyer (1960b), and in part by iterative procedures, using soil water extraction as determined by gravimetric sampling and phenological data from an experimental site within the region. Sufficient data were available to enable the formulation of functions for cotton, grain sorghum, and wheat. The model takes account of prevailing agronomic practices and dynamic aspects of crop growth and development, and makes provision for future refinements in available data. (Auth.)
MODEL TYPE: parametric
COMMENT: Model could form the basis of an assessment model with the introduction of appropriate response functions.

<70>
Fogel, M.M., L. Duckstein, and C.C. Kisiel. 1974. Modeling the hydrologic effects resulting from land modification. Trans. of the ASAE 17:1006-1010.
MODEL TYPE: parametric
COMMENT: Technology effects on land use change and hydrologic consequences could be examined.

<71>
Follett, R.F., R.R. Allmaras, and G.A. Reichman. 1974. Distribution of corn roots in sandy soil with a declining water table. Agron. J. 66:288-292.
ABSTRACT: The purpose of this study was to relate the distribution of corn (ZEA MAYS L.) roots to depth of a declining water table in a sandy soil association. Knowledge of root response to declining water tables is important for proper crop production management. Roots from 10 monoliths (91 cm deep), centered over and perpendicular to the corn row, were obtained at about full silk (August 26) from corn growing in 91-cm rows. Water table depths ranged from 1.33 to 2.64 m at silking after declining at the rate of about 1.3 cm/day since July 1. About 20% of the evapotranspiration was supplied by natural precipitation with the remaining 80% from soil water depletion and the water table for the period from July 1 to September 16 (final harvest). Shoot growth was maximum at intermediate water table depths. An equation describing root distribution was obtained from a regression fit of root depth (Y) as a function of water table depth (X(1)) and cumulative root weight (X(2)). A similar fit was made using root length as X(2). In no case was more than 10% of the total measured root weight or more than 20% of the total measured root length below 75 cm. The distribution of roots with depth indicates water requirements for corn in these sandy soils must be supplied to a root zone with maximum depth of about 100 cm. Retarded root growth was observed where soil oxygen diffusion rate (O.D.R.) was less than 26 g/cm**2/10**8 min. Such O.D.R. values were obtained at depths greater than 30 cm at the shallow water table site. Apparent normal root development occurred when O.D.R. values were greater than 30 g/cm**2/10**8 min and matric suctions were about 100 mb. (Auth.)
MODEL TYPE: regression equation
COMMENT: Function fitted to experimental results could be used in whole plant model.

<72>
Frenkiel, F.N., and P.S. Klebanoff. 1975. On the lognormality of the small-scale structure of turbulence. Bound.-Layer Meteorol. 8:173-200.
ABSTRACT: Higher-order moments of turbulent velocity gradients and their behavior with Reynolds number were measured in the nearly isotropic turbulent field generated by a square-mesh grid and in a turbulent boundary layer along a flat plate with zero pressure gradient. Hot-wire anemometry and instrumentation combining analog and digital methods were used to measure moments up to the fourteenth order. Measurements of such high-order moments required that particular attention be given to their validity. Involved herein was the evaluation of such effects as nonlinearity, averaging intervals, and the adequacy of the statistics for the tails of the probability density distributions. The results obtained are compared with those of other investigators for a variety of flow configurations in the laboratory as well as in the atmosphere. The concept of the intermittency of the small-scale structure and the theoretical approach involving lognormality of the probability density distribution of the dissipation rate are evaluated. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Theoretical analysis with no assessment application in present form.

<73>
Frere, M.H., C.A. Onstad, and H.N. Holtan. 1975. An agricultural chemical transport model. ARS-H-3, Agric. Res. Ser., USDA.
ABSTRACT: The use of chemicals is an important feature of modern agriculture, but the movement of the chemical from its point of application constitutes a potential hazard. The evaluation of this hazard is very difficult because the agricultural watershed contains many complex processes that dynamically respond to weather elements. To aid in evaluating this hazard, a mathematical model has been developed and a computer program written that describes the movement of chemicals in and across an agricultural watershed. For each storm in series the objective is to use the model to predict the concentration of a chemical in the runoff water, the total amount carried by the runoff water and sediment, and the location and concentration of the chemical remaining on the watershed. This report describes the rationale used to develop the model as well as a couple of tests of the model that illustrate and evaluate its use. (Auth.)
MODEL TYPE: parametric
COMMENT: Very useful in assessment of pollutant transport from technology sources. The chemical transport has been added onto the hydrologic simulator of Holtan and Lopez (1971).

<74>
Prissel, M.J., P. Poelstra, and P. Reiniger. 1970. Chromatographic transport through soils, III. A simulation model for the evaluation of the apparent diffusion coefficient in undisturbed soils with tritiated water. Plant Soil 33:161-176.
ABSTRACT: A simulation model, written in CSMP, is described permitting the calculation of chromatographic transport in heterogeneous systems like soils. Breakthrough curves of tritiated water were determined on undisturbed, water-unsaturated soil columns (100 cm length, 12 cm diam.). With the model, tortuosity and dispersion factors were calculated for three soils - a sand, a clay and a loess. The mean values for the tortuosity were 0.3, 0.2, and 0.2 and for the dispersion 0.7, 0.8, and 6 cm, for the three soils respectively. From these values it appears that usually dispersion is the main factor in forming the distribution pattern in soil, the contribution of ionic diffusion

APPENDIX A
Agricultural Models (continued)

<74> CONT.
being rather small. In many cases good approximative values of the dispersion coefficient may be obtained with an analytical solution of the chromatography equation assuming an averaged homogeneous system. / (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be useful in testing protocols for pollutant chemicals from energy technologies.

<75>
Gates, D.M. 1965. Energy, plants, and ecology. Ecology 46:1-13.
ABSTRACT: The environmental factors affecting the flow of energy between a plant and its environment are described. These factors are solar and thermal radiation, air temperature, water vapor density of the air, and wind speed. The mechanisms of radiation, convection, and transpiration which transfer energy between the plant and the environment are expressed in analytical form. An example is given of a 24-hour cycle for a plant illustrating the daily variation of each of these factors and of the resulting plant temperature. Basic plant properties, such as absorptance to radiation, convection coefficient, and water vapor diffusion resistance, determine the extent to which the environment influences the energy content and temperature of the plant. Photosynthesis is light and temperature dependent, and other physiolcgical processes are temperature dependent only. Maxima and minima in photosynthetic activity occur during a day as a consequence of changes in light intensity and leaf temperature produced by varying environmental conditions. The ecological significance of these environmentally influenced physiological processes is enormous in terms of productivity and competition. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Basic principles of energy transport and transformation. Work can be adapted to evaluation of technology impacts.

<76>
Gerwitz, A., and E.R. Page. 1974. An empirical mathematical model to describe plant root systems. J. Appl. Ecol. 2(2):773-781.
ABSTRACT: A survey has been made of the literature in which the root systems of vegetable crops, cereals and grasses have been investigated by various techniques, including excavation and the use of radioactive tracers. An empirical model was used to standardize the data. One form of the model is - P=100*(1-e**(-fx)) - in which P represents the percentage of roots contained in a depth of soil x cm. f is a parameter, such that 1/f is equal to the depth of soil which contains 63% of the total root mass. The effects of soil moisture, fertility, plant age, weight and species as f are considered. Seventy one out of the 101 sets of data fitted the model very satisfactorily. It is expected that the model will be useful in constructing mathematical models to simulate plant growth. (Auth.)
MODEL TYPE: regression equation
COMMENT: Derived function could be used in whole plant growth models.

<77>
Gilbert, O.L. 1970. A biological scale for the estimation of sulphur dioxide pollution. New Phytol. 69:629-634.
ABSTRACT: By observing the distribution of lichens and bryophytes in an area where levels of SO(2) are well known it has been possible to produce a scale from which annual average levels of this pollutant can be estimated. Instructions on how to use the scale are given and its accuracy and possible usefulness are discussed. (Auth.)
MODEL TYPE: response of indicator plants
COMMENT: Useful field survey tool.

<78>
Ginsburg, H. 1971. Model for iso-osmotic water flow in plant roots. J. Theor. Biol. 32:147-158.
ABSTRACT: The different interpretations of iso-osmotic water flow in plant roots are reviewed and a model based on the symplasm theory is proposed to explain this phenomenon according to the thermodynamics of irreversible processes. Analysis of data from the literature with the model lead to the following conclusions: (1) different reflection coefficients (sigma) at the symplasm boundary membranes are sufficient to account for the inwardly directed iso-osmotic water flow observed in maize roots; (2) the difference between the hydraulic conductivities (Lp) and the difference between sigma Lp at the boundary membranes can either increase or decrease iso-osmotic water flow depending on external conditions (i.e. hydrostatic pressure, concentration of permeable and impermeable solutes); (3) the model is consistent with anatomical and physiological data from the literature and it also explains how metabolism is involved in iso-osmotic water flow. The probable importance of iso-osmotic water flow for whole plants is briefly discussed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Detailed model of cellular processes that is not suitable for technology assessment.

<79>
Goudriaan, J., and P.E. Waggoner. 1972. Simulating both aerial microclimate and soil temperature from observations above the foliar canopy. Neth. J. Agric. Sci. 20:104-124.
ABSTRACT: A simulation model is described for the daily course of microclimatic characteristics of foliar canopy and the soil underneath. The independent driving forces are the meteorological observations above the canopy. The canopy is described by its geometrical, optical and physiological properties, the soil by its thermal and hydraulic properties. Comparison with real data shows a good agreement for crop transpiration, soil evaporation and soil heat flux, and to a lesser degree for air temperature and humidity and leaf temperature. The simulations, covering a full day, were executed with a stratified model. The effect of stratification was investigated by a comparison with a model continuous in height. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Very useful model that could evaluate microclimate changes induced by technology.

<80>
Green, R.E., and J.C. Corey. 1971. Calculation of hydraulic conductivity: A further evaluation of some predictive methods. Soil Sci. Soc. Am. Proc. 35:3-8.
ABSTRACT: A computational method based on the pore-interaction model of Marshall was shown to compare favorably with modified methods of Millington and Quirk and of Marshall for prediction of hydraulic conductivity vs. water content on a number of soils and a glass bead system. All methods required

APPENDIX A
Agricultural Models (continued)

<80> CONT.
matching one point on the calculated hydraulic conductivity curve to an experimentally measured hydraulic conductivity value. The calculation method adequately predicted the experimentally measured values and provide satisfactory conductivity data for many applications. An advantage of the proposed method is its independence of the value chosen for the exponent on the porosity term in the prediction equation. (Auth.)
MODEL TYPE: mechanistic
COMMENT: The method is useful in soil water flow models for representation of soil hydraulic properties.

<81>
Gregorius, H.R., and G. Muller. 1975. Genetic structures in finite, open-pollinated plant populations: A model and its application to seed orchards. Theor. Appl. Genet. 46:295-305.
ABSTRACT: A model has been constructed to investigate the consequences of the rate of self-fertilization, pollen-dispersal, population-size, and number of clones on the genetic structure of finite seed plant populations. Derivations have been performed for two different cases: (A) Parental genetic structure explicitly given: inferences for the expected genetic structure of the resulting seed population; (B) Extension of case A to several non-overlapping generations. If random cross-fertilization is assumed for case A the genetic composition does not change and the genetic distance between the corresponding Hardy-Weinberg-structure and the expected offspring-structure is 0 if the rate of self-fertilizaton is equal to 1/N (N=population-size): any deviation from 1/N causes an increase in genetic distance. In case B the expected genetic structures have been derived for all generations and it was possible to establish a comparatively simple dependence on the coefficient of inbreeding. In addition the variance of the allele-frequency has been presented. All the above influential components can be summarized by a single quantity, called M. After proving that 1/M can be conceived as the effective population-size, all the results obtained could be presented depending on this effective size and the average rate of self-fertilization only. Applying the findings of the model to the situation realized approximately in a seed-orchard, the following statements can be made: Case (A) Again assuming random cross-fertilization, a deviation of the parental population from the corresponding Hardy-Weinberg-proportions can, with increasing rate of self-fertilizaton, be exceeded by the respective deviation of the seed population. Case (B) The influence of pollen dispersal on the effective population size has been investigated, assuming no variation of the individual rates of self-fertilization, pollen and seed production within the population. Only extremely small differences between effective and actual population size were obtained, which indicates that the influence of pollen dispersal is of minor importance in this case. For different rates of self-fertilization, significant differences in the increments per generation for the coefficients of inbreeding, as well as the frequency of homozygotes, were obtained for the first generation only. Decreasing number of clones influences the rate of self-fertilization and the effective population size simuletaneously by increasing the first and decreasing the latter. This is transferred to the coefficient of inbreding, frequency of the homozygotes and the variance of the allele-frequency by an increase of increments for all generations. (Auth.)
MODEL TYPE: statistical
COMMENT: Theoretical analysis not suitable for technology assessment in present form.

<82>
Grenetz, P.S., and A. List. 1973. A model for predicting growth responses in plants to changes in external water potential: ZEA MAYS primary roots. J. Theor. Biol. 39:29-45.
ABSTRACT: In response to osmotic step changes, three distinct phases have been noted in the growth response of ZEA MAYS primary roots. They are cessation or slowing of growth over a period of 15-20 minutes, tissue contraction, and a damped oscillatory return to nearly normal growth rate, all within a period of about one hour. A system model of the tissue response is presented to explain such behavior and to serve in a predictive capacity to govern future experiments. It is supposed that for turgor pressure in excess of a cell wall yield threshold, plastic flow is the major component of wall deformation, and that when turgor falls below yield threshold, elastic deformation is dominant. The equations of the model describe growth rate as a function of time in terms of the following properties; plastic flow, elastic deformation, permeability to water, and solute uptake. They are derived from basic equations of feedback interactions between internal osmotic pressure and growth rate, and between wall softening, turgor and growth rate. The model predicts oscillatory growth rate regulation, and phase and amplitude relationships between turgor pressure and growth rate. The simplest model which accounts for all observations is that of biphasic deformation, two modes of wall softening, and a dual feedback system involving osmotic and yield threshold control of growth rate. It should be noted that to predict the time course of turgor pressure, osmotic pressure, yield pressure, and growth rate, two initial conditions and six system parameter values are sufficient. So far only the initial values of growth rate and its derivative can be obtained for ZEA MAYS primary roots. However, values for wall softening and hardening coefficients (including the strain and turgor independent component), plastic extensibility, water permeability and dilution rate coefficients have not been obtained as yet for ZEA roots. Values for some of these parameters have been obtained for other roots, coleoptiles, and giant algal cells. Lest the reader despair, it should be pointed out that experimental observations coupled with simulation studies will help establish restricted ranges of values that the system parameters might assume. These can then be compared with known values in the literature and values experimentally obtained in the future. (Auth.)
MODEL TYPE: mechanistic
COMMENT: A basic plant physiological model of doubtful application in technology assessment.

<83>
Hackett, C., and D.A. Rose. 1972. A model of the extension and branching of a seminal root of barley, and its use in studying relations between root dimensions, II. Results and inferences from manipulation of the model. Aust. J. Biol. Sci. 25:681-690.
ABSTRACT: A model of root growth was used to investigate why the average length (l) of cereal root members remains roughly constant. Taking as a standard the model root which agreed with actual roots from an experiment,

APPENDIX A
Agricultural Models (continued)

<83> CONT.
the nine variables in the model were altered singly to see which had greatest influence on 1. The results showed that the constancy of 1 was due primarily to the existence of ceilings to the rates at which each class of root member can extend. These ceilings are thought to be determined by a property associated with the diameter of the root member. Also of importance was the timing of the onset of each order of branching. This timing was related to that at which the parent members, as a population, began to increase roughly linearly in volume. A tentative explanation of the concomitance is put forward. Understanding of the phenomenon was advanced by the study, but a full explanation was not achieved, mainly because of the lack of information about certain aspects of root development. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model evaluates plant physiological behavior of roots and is not readily applied to technology assessment.

<84>
Hackett, C., and D.A. Rose. 1972. A model of the extension and branching of a seminal root of barley, and its use in studying relations between root dimensions, I. The model. Aust. J. Biol. Sci. 25:669-679.
ABSTRACT: Previous papers have reported that relations between the total number, length, surface area, and volume of graminaceous root members tend to remain roughly constant during vegetative growth. Through the use of a model of the extension and branching of a seminal root of barley (HORDEUM VULGARE L.), which was developed for the purpose, an attempt has now been made to determine the properties of root growth responsible for the phenomenon. The present paper introduces the study and describes the model. The model takes advantage of the fact that the extension and branching of cereal root members grown in homogeneous media proceeds at approximately constant rates for lengthy periods. The overall dimensions of roots can therefore be determined by reference to formulae representing time and a limited number of properties of each type of root member. The validity of the model for the use intended is demonstrated by testing the underlying assumptions and checking the model against actual data. Other possible roles for the model are suggested. Part II of the series (Hackett and Rose 1972) reports the results and inferences from manipulation of the model. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model describes root growth and through change in parameters, environmental effects could be simulated.

<85>
Hanks, R.J. 1974. Model for predicting plant yield as influenced by water use. Agron. J. 66:660-665.
ABSTRACT: A model has been devised to predict plant yield, both total dry matter and grain, as a function of water use. The model is simple and inexpensive to run on a computer to determine seasonal yields as influenced by irrigation frequency and amount, rainfall, and soil water storage. A good fit of predicted vs. measured dry matter yield of sorghum (SORGHUM VULGARE L.) in Colorado, corn (ZEA MAYS L.) dry matter and grain yields in Israel, and corn grain yields in Nebraska, with various water application treatments, was found. A basic assumption is that the ratio of actual to potential dry matter yield is directly related to the ratio of actual to potential transpiration. Evaporation from the soil is assumed to decrease with the square root of time after wetting as well as with the stage of growth. The shape of the relative yield-water use curve was found to be sensitive to the evaporation and transpiration assumptions made, but insensitive to the relation used to describe the influence of soil water status on transpiration. (Auth.)
MODEL TYPE: parametric
COMMENT: Empirical model with broad application to technology effects on crop production. Could be readily adapted to evaluate irrigation with blowdown water, although salinity effects would need to be included.

<86>
Hansen, G.K. 1975. A dynamic continuous simulation model of water state and transportation in the soil-plant-atmosphere system, I. The model and its sensitivity. Acta Agric. Scand. 25:129-149.
ABSTRACT: Through a continuous simulation model, a synthesis of quantitative interrelations of water state and transportation in the soil-plant-atmosphere system is described for a growing crop under realistic field conditions. In the model, vertical water flux in the soil is based on Darcy's law for flow in porous media. Water flow is based on Gardner's model (1960) for water flow to single roots, but modified to steady rate. The physiological plant parameters are based on experimentally derived functions. The atmospheric part of the model is based on the model of Monteith (1965). The model is written in DYNAMO II. The simulation runs with a fixed time interval of 0.001 day. The behaviour of the model is demonstrated by a growth period of 20 days without precipitation. Results of the simulation are shown for two different soils and at three values of evaporative demand. It is concluded that the model is able to predict water state and water flow in soil and plant, quantitatively as well as qualitatively.
MODEL TYPE: mechanistic
COMMENT: Model is research oriented and expensive to run. Not recommended for assessment.

<87>
Hari, P. 1972. Physiological stage of development in biological models of growth and maturation. Ann. Bot. Fennici 9:107-115.
ABSTRACT: Time is frequently used to describe the developmental stage of a plant or animal in biomathematical models. However, there is often a notable discrepancy between the chronological age and 'the biological age' of an organism, owing to different rates of development under different environmental conditions. In the present paper a variable is defined that should serve better than age to denote the stage of development. The physiological stage of development defined here can be used to construct and test various hypotheses concerning growth and development. As an example, an application of the physiological stage of development to a mathematical model of the daily increment of pine seedlings is presented. The same variable (physiological stage) should be equally useful in many other biological models. (Auth.)
MODEL TYPE: parametric
COMMENT: Empirical model that can be used in comprehensive plant models to represent plant development.

<88>
Harris, G.P. 1972. The ecology of corticolous lichens, III. A simulation model of

APPENDIX A
Agricultural Models (continued)

<88> CONT.
productivity as a function of light intensity and water availability. J. Ecol. 60:19-40.
ABSTRACT: A mathematical simulation model for predicting epiphytic corticolous lichen productivity has been built relating lichen productivity to environmental conditions at Shaugh, S. Devon. Net carbon assimilation rates were calculated for PARMELIA CAPERATA (L.) Ach. at six heights in a model oak tree, for a simulated time period of 2 years. Weekly totals of net carbon assimilation were calculted for lichens at each height. The model has been constructed as a series of blocks each of which relates to, and was tested against, observed field data. These blocks are as follows. (a) Main program - responsible for setting up arrays, reading data and calling subroutines. (b) Radiation intensity subroutine - using input parameters of time of year, time of day, cloud cover and radiation drop inside the tree canopy; radiation levels were calculated for each of the six height zones in the tree. (c) Wetting-up subroutine - rates of wetting of different parts of the tree during rain were observed in the field using paper-grid conductivity sensors and a portable 12-track chart recorder. A new technique for modelling rainfall/throughfall was used to simulate the wetting-up system and was tested against observed data, with good agreement. (d) Measurements of evaporation were carried out in the field using the paper-grid conductivity sensors and small capillary evaporimeters. Calculations of evaporation by Penman's method were used to estimate evaporation rates from the entire tree canopy. Various methods of apportioning the evaporation rates within the canopy are discussed. (e) Calculations of thallus physiology are based on data published in a previous paper in this series. The model appears to give a calculated result which compares favourably with the vertical distribution of P. CAPERATA measured in the field. Variation in weekly net carbon assimilation totals are shown to be highly variable and are thought to be correlated with water availability in the environment. Changes in the vertical evaporation gradient are shown to have a strong effect on the vertical distribution of this species. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful model that could be adapted to simulate pollutant effects. Results could be compared with field surveys of lichens which are good pollutant indicators. This model has indirect application to technology impacts on agricultural ecosystems.

<89>
Heck, W.W., and D.T. Tingey. 1971. Ozone. Time-concentration model to predict acute foliar injury. Proc. Second Int. Clean Air Congr., pp. 249-255, Academic Presss, New York.
MODEL TYPE: parametric
COMMENT: An equation which predicts acute effects of pollutants on plants where both time and concentration are independent variables. Relationship could be included in more comprehensive plant models.

<90>
Helmy, A.K., E.A. Ferreiro, and N. Peinemann. 1975. Plant roots as multi-zonal membranes. Z. Pflanzenphysiol. 76. S: 294-299.
ABSTRACT: By using plant roots of barley, wheat, tall wheatgrass, peas and cucumber as membranes in a concentration cell in which the same KCl concentration is placed on both sides of the root, it was found that for all the plants the measured electric potentials are positive at low KCl concentration, they become negative at high KCl concentration and vanish at an intermediate KCl concentration. The data could be explained by a theoretical model that treats the root as a multizonal membrane, i.e. composed of zones with different electrochemical properties. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Basic plant physiological model with no application to assessment at this stage.

<91>
Hem, J.D. 1976. Geochemical controls on lead concentrations in stream water and sediments. Geochim. Cosmochim. Acta 40:599-609.
ABSTRACT: The equilibrium distribution of lead in solution and adsorbed on cation exchange sites in sediment theoretically may be calculated from equations representing selectivities of substrate for lead over H^+, $Ca^{(2+)}$ and Na^+, and the stabilities of lead solute species. Such calculations include consideration of total concentrations of major ions, cation exchange capacity (CEC) of substrate, and pH, at values expected in various natural systems. Measurements of CEC and selectivity coefficients were made for synthetic halloysite, a finely divided amorphous 1:1 clay prepared by precipitation from a mixture of solutions of aluminum and silica. Where suspended sediment having the same properties is present in concentrations of 10-1,000 mg/l at pH 6-8, more than 90% of the lead present can be adsorbed on sediment surfaces. The cation exchange behavior of lead and other minor cationic species in natural systems could be predicted by this type of model if enough other supporting information were available. Information of the type needed describing natural stream sediments, however, is presently inadequate for accurate predictions. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful model that may have too much detail for assessment purposes.

<92>
Hexem, R.W., V.A. Sposito, and E.O. Heady. 1976. Application of a two-variable Mitscherlich function in the analysis of yield-water-fertilizer relationships for corn. Water Resour. Res. 12:6-10.
ABSTRACT: Variations of models developed by E.A. Mitscherlich in the early part of this century are periodically used for estimating input-output relationships for plants. Mitscherlich's work focused on a single variable. While these exponential models incorporate features of theoretical appeal, the procedures for quantifying the models are relatively complex when two or more independent variables are included. In fits of Mitscherlich and polynomial forms to yield-water-fertilizer data for corn grown under experimental conditions in Colorado and Kansas, test statistics for the polynomial forms are as good as or better than those for the more complex Mitscherlich models. (Auth.)
MODEL TYPE: parametric
COMMENT: Empirical function that could be used in a plant solute uptake model. The function has limited use for assessment as it stands.

<93>
Hillel, D., H. Talpaz, and H. van Keulen. 1976. A macroscopic-scale model of water uptake by a nonuniform root system and of water and salt movement in the soil profile. Soil Sci. 121(4):242-255.
ABSTRACT: A dynamic numerical model, based on the transport equations for water and noninteracting solutes in a porous medium and

APPENDIX A
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<93> CONT.
written in IBM S/360 CSMP language, was designed to compute the movement of water and salts in a soil profile in the presence of an active root system. The inputs are: soil and root system hydraulics, initial water content and solute concentration, density and distribution of active roots in the soil profile, and the climatically imposed evapotranspiration rate with its diurnal fluctuation. The output provides the patterns of soil moisture depletion and of water potential distribution in the soil and the water potential in the plant as needed to maintain various transpiration rates, as well as the flow of water and salt through the bottom of the root zone. The model is illustrated for a number of combinations of root densities and resistances, profile depths, initial soil water contents, solute concentrations, and evaporativity levels. The pattern of soil moisture depletion and plant-water status is seen to be a combined function of soil, plant, and climatic factors which can be mapped out systematically and quantitatively by dynamic simulation, for a wide range of environmental conditions. However, much experimental research is yet required to obtain the appropriate input information for models of this kind and to validate their results. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful in evaluation of technology impacts on soil water and chemical movement although experimental input data are required as noted by the authors.

<94>
Hillel, D., C.G.E.M. van Beek, and H. Talpaz. 1975. A microscopic-scale model of soil water uptake and salt movement to plant roots. Soil Sci. 120:385-399.
ABSTRACT: A numerical model, based on the transport equations for water and noninteracting solutes and written in IBM S/360 CSMP language, was designed to compute the radial movement of water and salts to plant roots. The inputs are: the soil's suction and conductivity functions, the soil solution's content and concentration, root density and permeability, and the required uptake rate (whether constant or diurnally fluctuating). The output provides the time-dependent drawdown of matric and osmotic potentials in the immediate vicinity of the root, the gradients and flow rates of water and solutes in the soil, and the plant water potentials needed to maintain different uptake rates. The model is illustrated for various rooting densities and various initial water contents and salt concentrations. The effect of increasing root density and permeability is seen to be similar to the effect of increasing water content or reducing transpirational demand. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Work is too detailed for assessment purposes.

<95>
Hillel, D.I., C.H.M. van Bavel, and H. Talpaz. 1975. Dynamic simulation of water storage in fallow soil as affected by mulch of hydrophobic aggregates. Soil Sci. Soc. Am. Proc., 39(5):826-833.
ABSTRACT: A mechanistic numerical model, based on fundamental physical principles and written in IBM S/360 CSMP language, was designed to compute the dynamic balance of water in a fallow soil through repeated cycles of infiltration and evaporation. The necessary inputs are: (i) hydraulic characteristics of the soil and of the surface crust or mulch layer; (ii) duration and intensity characteristics of rainstorms or irrigations; and (iii) the potential evaporation rate as it varies diurnally and from day to day. The output provides time-dependent rates and cumulative quantities of infiltration, runoff, surface detention, evaporation, internal drainage, and changes in water content of different layers and of the profile as a whole. Computations carried out for a 4-day simulation (including two rainstorms and four evaporation cycles) illustrate the use of the model for uniform, crusted, or mulched soil; and predict that the presence of a mulch of hydrophobic aggregates, several centimeters thick, can greatly increase the quantity of water absorbed and retained in the profile. This finding accords with previously published experimental results and indicates a promising approach to soil management for water conservation in dryland and irrigated farming. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be used in infiltration analysis including the effects of crusting of soil surface.

<96>
Holford, I.C.R., and G.E.G. Mattingly. 1976. A model for the behaviour of labile phosphate in soil. Plant Soil 44:219-229.
ABSTRACT: The Langmuir two-surface adsorption equation is used to derive a phosphate adsorption characteristic, the maximum buffer capacity, which integrates the intensive and extensive components of adsorption and is independent of P saturation. Changes in the intensities and quantities of labile P and equilibrium buffer capacities resulting from fertilization of a group of 24 soils are shown to be related to the Langmuir high-energy adsorption parameters and in particular the maximum buffer capacity. (Auth.)
MODEL TYPE: mechanistic
COMMENT: The function can be used in more comprehensive soil water-solute transport models.

<97>
Holford, I.C.R., R.W.M. Wedderburn, and G.E.G. Mattingly. 1974. A Langmuir two-surface equation as a model for phosphate adsorption by soils. J. Soil Sci. 25:242-255.
ABSTRACT: For forty-one soils (pH greater than 5.0) from southern England and eastern Australia, the Langmuir equation was an excellent model for describing P adsorption from solutions less than 10**(-3) M P, if it was assumed that adsorption occurs on two types of surface of contrasting bonding energies. For most of these soils, which were relatively undersaturated with P, more than 90% of the native adsorbed P occurred on the high-energy surface. (Auth.)
MODEL TYPE: mechanistic
COMMENT: The proposed function can be readily included in soil chemistry models. The empirical constants need to be evaluated for the soil of interest.

<98>
Huggins, L.P., J.R. Burney, P.S. Kundu, and E.J. Monke. 1973. Simulation of the hydrology of ungaged watersheds. Technical Report No. 38, Purdue University Water Resources Research Center, West Lafayette, IN.
ABSTRACT: The overall objective of the research project reported herein was the development of a watershed model capable of accurately predicting hydrologic behavior of natural watersheds for which data concerning historical relationships between rainfall and

APPENDIX A
Agricultural Models (continued)

<98> CONT.
runoff events are unavailable, i.e. ungaged catchments. This objective was accomplished by a combination of laboratory studies related to overland flow and of the continued development of a watershed model using computer simulations of real storm events on gaged catchments to determine a range of appropriate parameter values for the model. The computer program used to implement the watershed model together with sample data and its output is given. The watershed model developed in the research reported below uses a distributed analysis approach rather than the more commonly employed lumped system analysis. The model involves the subdivision of a catchment into a grid of small elemental areas, the mathematical characterization or modelling of the various physical processes occurring within each element and the numerical integration of the responses from each watershed element into a comprehensive description of not only the discharge at the outlet, but of the complete hydrologic response of every element of which the catchment is composed. The primary advantages of the distributed watershed model are its potential for increased accuracy due to its inherent capability to evaluate spatially variable factors within a watershed and its comprehensive description of the total watershed behavior. This latter advantage is of increasing importance in providing a means of evaluating, in a very broad context, the potential environmental effects of alternate programs for resource development. The primary disadvantage of distributed models is the greatly increased computational effort required to utilized them. However, large computers have largely removed the economic limitations associated with this approach, at least for relatively small watersheds. (Auth.)
MODEL TYPE: parametric
COMMENT: Potentially very useful in assessment since it can allow evaluation of situations with limited data sources. Applications to agricultural watersheds are included.

<99>
Incropera, F.P. 1975. Leaf photosynthesis: The influence of environmental variables. J. Environ. Qual. 4:440-447.
ABSTRACT: A model is presented for the effects of light intensity and ambient temperature, relative humidity, and carbon dioxide concentration on leaf photosynthesis. The model treats diffusion and chemical processes occurring within the leaf, as well as the transfer of mass and energy between the leaf and its environment. Calculations have been performed for ZEA MAYS L. (maize) which suggest the influence of environmental changes. Although leaf energy exchange processes act to moderate the effect of changes in the atmospheric temperature, a severe cooling trend may cause as much as 20% reduction in photosynthesis. Under most conditions, the rate of photosynthesis is further diminished by a reduction in relative humidity. In contrast, a 20% increase in the atmospheric CO(2) concentration, which if projected for the year 2000, will increase photosynthesis by approximately 15%. The calculations also suggest optimum ambient conditions for controlled growth environments, such as a greenhouse. In addition tc a saturating light intensity of approximately 700 W/m**2, these conditions include a temperature and relative humidity of approximately 30C and 90%, respectively, and a CO(2) concentration of approximately 1,500 ppm. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological research model with too much detail for assessment purposes.

<100>
Jackson, J.E., and J.W. Palmer. 1972. Interception of light by model hedgerow orchards in relation to latitude, time of year and hedgerow configuration and orientation. J. Appl. Ecol. 9:341-357.
ABSTRACT: Light interception by model hedgerow orchards and light distribution over their surfaces were investigated using a computer for the direct light calculations and a graphical technique to study the distribution of diffused light under both uniformly luminous and standard overcast skies. Model hedgerows of triangular, truncated triangular, and rectangular section, each with three different ratios of hedgerow height to alleyway width were considered at latitudes 51.3 deg., 45 deg. and 34 deg. N. When only half the ground area is covered with hedgerow and the hedgerow height is equal to the alleyway width, over 80% of available light can be intercepted. As the ratio of hedge height to alley width is increased, direct light interception is increased in much smaller proportion. Light interception is reduced with decreasing angle of the hedge sides to the horizontal and at lower latitudes especially for east-west oriented hedgerows. While there is little change in percentage interception by north-south oriented hedges as the season progresses, there is a marked seasonal pattern of interception by east-west hedges and this varies with latitudes. As hedge height is increased so is the proportion of poorly illuminated surface and as the angle to the horizontal is decreased the evenness of illumination over a hedgerow side is increased. Illumination of the south faces of east-west hedges is relatively evenly distributed, the uniformity being greater for short than tall hedges, sloping than vertical sides and at low latitudes than at high latitudes, but it varies considerably with time of year for some hedgerow configurations. Interception and distribution of diffuse light is rather similar to that of direct light for north-south hedgerows. The effects of latitude on light interception and distribution over hedgerow systems of differing proportions appear large enough to influence significantly the value of different systems of planting. This will apply to other row crops as well as hedgerow orchards. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be used to evaluate shading effects of structures on agricultural systems.

<101>
Jahnke, L.S., and D.B. Lawrence. 1965. Influence of photosynthetic crown structure on potential productivity of vegetation, based primarily on mathematical models. Ecology 46:319-326.
ABSTRACT: Productivity studies have shown that plants with marked vertical extension of photosynthetic crown can be more productive per unit area of land or water occupied than plants whose photosynthetic surface is spread in a thin horizontal sheet on the earth's surface if environmental factors are not otherwise limiting. Geometric models including a flat disc and cones of several heights but constant base radius show that heightening cones intercept progressively more light. Amount of chlorophyll displayed per unit area of earth's surface can also increase greatly with vertical extension of aerial crown. These observations suggest that thickness, geometric configuration, and chlorophyll content of the photosynthetic

APPENDIX A
Agricultural Models (continued)

<101> CONT.
portion of the vegetation per unit area of earth's surface, and light intensity incident on surfaces at right angles to sun's rays should be measured and described as basic data in primary productivity studies. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Probably not useful since other more comprehensive models are available.

<102>
Jakobsen, B.F. 1973. Interrelations of soil physical characteristics. Acta Agric. Scand. 23:165-172.
ABSTRACT: Water retention, hydraulic conductivity, and oxygen diffusion at different soil bulk densities, and soil compactability at different water contents of a loam soil were measured. Thermal characteristics were calculated at different bulk densities and water contents. Mathematical expressions for the relations and interrelations were found for the use in construction of models for plant growth, and for an attempt to optimize the soil structure for plant growth under given climatical conditions. The system may be applied to other soils not too low in clay content and offers possibilities of surveying and handling the problems of changes in soil structure. Derivates of the interrelations between soil factors may yield good estimates of changes in soil conditions caused by a change in one factor. (Auth.)
MODEL TYPE: parametric
COMMENT: Approach provides a means of estimating soil properties usually required in detailed soil process models and thus, is useful in extending the range of modeling applications where limited soil data are available.

<103>
Janssen, J.G.M. 1974. Simulation of germination of winter annuals in relation to microclimate and microdistribution. Oecologia (Berl.)14:197-228.
ABSTRACT: A simulation program on the germination of winter annuals is written in such a way that the influence of changing environmental conditions on germination characteristics such as the time of germination, the percentage of germination and the distribution function of germination is described as well as possible in accordance with experimental data. The changing environmental conditions are simulated by a program that describes the changes of the microclimatological characteristics, temperature and moisture content of the soil, during a number of days depending on local conditions and macro-meteorological data. The simulated differences in germination between the two winter annuals VERONICA ARVENSIS L. and MYOSOTIS RAMOSISSIMA Rochel ex Schult. at different sites are discussed in relation to differences in their microdistribution. A way is indicated to characterize in ecological studies the microclimatlogical situation of a site in the field. (Auth.)
MODEL TYPE: mechanistic
COMMENT: The representation of temperature and water effects on germination could be used in assessment studies.

<104>
Jones, J.W., R.F. Colwick, and E.D. Threadgill. 1972. A simulated environmental model of temperature, evaporation, rainfall and soil moisture. Transactions of the ASAE 15(2):366-372.
ABSTRACT: Weather is a primary forcing function for decisions concerning crop production. Plant models have been developed to simulate plant production based upon the weather that is imposed upon the "computer plant". For studying a complete crop production system, it is desirable to have an environmental model to provide simulated field conditions for a particular location in which the "computer plant" is to be grown. This study was designed to develop an environment model for crop production or other biological systems to provide inputs of daily rainfall, temperature, evaporation, and soil moisture variations with depth. Review of the literature revealed that studies had been conducted to describe temperature and rainfall distributions at other locations although no similar work was found for evaporation distribution. Studies involving unsaturated soil moisture transfer were found but most of these studies were confined to laboratory conditions. The systematic combination of results from the previous studies with results from this research provided a model for simulating these selected environmental parameters under natural conditions. Functional relationships were developed for each environmental factor. These relationships indicated the interdependence among the variables of temperature, rainfall, evaporation, and soil moisture content. Actual weather records for State College, Miss., were used to develop models for the weather simulation. In general, rainfall and time in the year were important in simulating weather variables. It was found that daily rainfall amounts did not follow any seasonal trend for State College, but rainfall probabilities did depend upon the time in year. The Monte Carlo method of simulation was used to account for influences of other variables not considered in the hypothesized functional relationships. The weather model was run on the computer and 10 years of simulated data were shown to compare very closely with observed data for State College. The soil moisture model produced results that fell within 10 percent of the observed data for at least 43 days. It was concluded that the models developed in this paper can be used to provide basic environmental variables for use in crop production simulations for studying complete systems at various locations. The methods of simulation developed in this paper show promise for studying and projecting environmental factors. (Auth.)
MODEL TYPE: stochastic
COMMENT: Useful rainfall and temperature simulator developed for Mississippi conditions. Valuable for assessment.

<105>
Jurinak, J.J., S.H. Lai, and J.J. Hassett. 1973. Cation transport in soils and factors affecting soil carbonate solubility. EPA-R2-73-235, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, P.O. Box 1198, Ada, OK 74820.
ABSTRACT: A predictive model of cation transport in soils was developed and tested. This model involved the definition of the cation exchange process in soil columns during the miscible displacement of cation solutions. A mass balance equation was formulated which included a general nonlinear exchange function. The solution of the equation was accomplished by numerical methods. The method was applied to the transport of cations through an exchanger using five different types of exchange functions. The model was further tested by conducting soil column studies where both homovalent and heterovalent exchange occurred. The agreement between predicted cation transport in soils and experimental data was good.

APPENDIX A
Agricultural Models (continued)

<105> CONT.
Laboratory studies were also conducted, using the carbonate saturometer, to assess the effect of Mg+2 ion on the solubility of calcareous materials. Carbonate solubility in the presence of Mg+2 ion was found to vary with the surface area of the solid phase, the mineralogy of the carbonate material, and the degree of saturation of the water with respect to a given carbonate mineral. Calcite generally increased in solubility, when Mg+2 was present, in waters which were unsaturated with respect to calcite. Carbonate material which contained magnesium as a constituent ion, e.g., dolomite, decreased solubility as Mg+2 concentration increased in waters which were near saturation with respect to colomite. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model applies to saturated conditions and could be used for assessment of flooded soils and groundwater impacts of technology.

<106>
Kabel, R.L., R.A. O'Dell, M. Taheri, and D.D. Davis. 1976. A preliminary model of gaseous pollutant uptake by vegetation. CAES Publication No. 455-76, Center for Air Environment Studies, The Pennsylvania State University, University Park, PA 16802.
ABSTRACT: The objective of this research is to investigate the various mechanisms and factors which control gas uptake by vegetation and to develop quantitative methods for predicting the uptake rate. Sulfur dioxide (SO(2)) is used as an example pollutant of interest. First, the three resistances to uptake - aerodynamic, stomatal, and mesophyllic - are described and then characterized in terms of controlling parameters. This approach to gas exchange has been used by plant physiologists since Gaastra (1959) or earlier. Factors which control the individual leaf aerodynamic resistance, r(a), are wind speed, leaf size and geometry, and gas viscosity and diffusivity. The stomatal resistance, r(s), is a function of the stomatal opening, which in turn is affected by water deficit, CO(2) concentration, and light intensity. The mesophyllic resistance, r(m), is related to gas solubility in water, gas-liquid diffusion, and ultimate removal of the gas by leaf hydrodynamics and chemical reactions. The three resistances, which are based on the leaf surface, are summed and divided into the atmospheric gas concentration difference to yield the uptake rate per unit leaf area. Therefore, if the leaf characteristics and environmental parameters which control the resistances - wind speed, atmospheric moisture, temperature, and light intensity - are known, the gas uptake rate by the leaf can be estimated. As an initial test of the model, estimates of gas uptake by vegetation are compared with published results. When the uptake rate by leaves is known, the removal of SO(2) or other pollutant gases over vast vegetated tracts may be calculated. Then, the impact of vegetation, considered as a natural sink for atmospheric pollutants, can be assessed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful model for assessment purposes.

<107>
Kallis, A., and H. Tooming. 1974. Estimation of the influence of leaf photosynthetic parameters, specific leaf weight and growth functions of yield. Photosynthetica 8(2):91-103.
ABSTRACT: Changes in the growth rate and in the crop grain yield due to the variations in parameters of photosynthetic and respiratory functions, and the specific leaf weight and growth functions of different organs of plants at various regimes were studied under the assumption that other environmental conditions were not limiting. The system of growth equations derived by Ross (1967) and the mathematical model of plant productivity which took into account adaptation to irradiance were used in crop growth and yield analyses. As an example yield calculations were made with growth functions of barley (HORDEUM VULGARE L. cv. Domen) as basic parameters. According to these calculations an increase in grain yield may be expected only at optimum combinations of the photosynthetic activity, respiratory economy, specific leaf weight of leaves and growth functions, providing an optimum leaf area index of crops and their high net photosynthetic rate as a whole. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model contains physiological detail and is applicable to research on photosynthesis.

<108>
Katznelson, J. 1977. Phosphorus in the soil-plant-animal ecosystem. Oecologia (Berl.) 26:325-334.
ABSTRACT: A compartmental model of phosphorus in soil-plant-animal ecosystem is described. It consists of 17 compartments, five in soil, six in plant, three in aboveground fauna and three in soil organisms and microorganisms. Common amounts and rates of turnover in each of these compartments is presented. Though the total amount of P in the ecosystem is large, only a very small part of it is being cycled, and presented data show that removal of P from an agricultural pastoral ecosystem is very slight. Most of the available phosphorus which is absorbed by plant roots is gradually fixed in forms of long-range unavailability, both by plants and by animals. This process of biological fixation is counterbalanced mainly by the activity of soil microorganisms. Quantities of input-output of P in intensive pastoral ecosystems are also presented, and some agronomical and ecological implications are considered. The manipulation of soil microorganisms and change towards more desirable P releasing strains or species may decrease need of fertilization, lower the risk of eutrophication and enhance productivity of such ecosystems. Such manipulations, however, can be achieved only after appropriate research. (Auth.)
MODEL TYPE: parametric
COMMENT: Model is tuned to data from literature and is used to investigate principles in ecosystem analysis. The method could be adapted to assessment purposes.

<109>
Kercher, J.R. 1977. GROW1: A crop growth model for assessing impacts of gaseous pollutants from geothermal technologies. UCRL-52247, Lawrence Livermore Laboratory, California.
ABSTRACT: A preliminary model of photosynthesis and growth of field crops was developed to assess the effects of gaseous pollutants, particularly airborne sulfur compounds, resulting from energy production from geothermal resources. The model simulates photosynthesis as a function of such variables as irradiance, CO(2) diffusion resistances, and internal biochemical processes. The model allocates the products of photosynthesis to structural (leaf, stem, root, and fruit) and storage compartments of the plant. The simulations encompass the entire growing season from germination to senescence. We describe the model conceptually and mathematically and provide

APPENDIX A
Agricultural Models (continued)

<109> CONT.
examples of model output for various levels of pollutant stress. Also, we outline future developments that would improve this preliminary model and discuss its applications.
MODEL TYPE: mechanistic
COMMENT: Very useful model development for assessment of air pollutant effects on crops with emphasis on the photosynthesis process.

<110>
Kercher, J.R., and H.H. Shugart. 1975. Trophic structure, effective trophic position, and connectivity in food webs. Am. Nat. 109:191-205.
ABSTRACT: A new measure of distance from the food source to any member of a food web is introduced. This measure is referred to as effective trophic position. Effective trophic position is defined as a function of energy ingested per unit time by a population and the production of the autotrophs necessary to maintain that population. Trophic position thus defined is a generalization of the trophic-level concept. An algorithm is developed to construct food webs with ecological constraints to examine statistical distributions of the standing crops and trophic positions in food webs. Ecological constraints are imposed on food chain length and on the range of transfer efficiencies in food webs. A Monte Carlo technique was used to generate model food webs with an arbitrary number of internal connections. The number of connections ranges from the minimum possible (corresponding to simple food chains) to the maximum possible (extremely connected food webs). The relationship between biomass and trophic position distributions of food webs were examined. The moments of these distributions are determined in part by the connectivity of food webs, and a possible application is the estimation of connectivity and trophic position distributions by measuring the biomass distributions. Regressions were found relating food-web connectivity to the moments of the biomass distributions and the distributions along the effective trophic position scale. The Monte Carlo results indicate that food web standing crops should be log Pearson Type I distributed. A similar result is found in field measures of food webs.
MODEL TYPE: stochastic
COMMENT: Theoretical analysis of food web model characteristics. Not directly applicable to technology assessment.

<111>
Kline, J.R. 1973. Mathematical simulation of soil-plant relationships and soil genesis. Soil Sci. 115:240-249.
ABSTRACT: Mathematical simulation is a technique drawn from the engineering disciplines which shows promise in dealing with some problems in soil-plant relationships and soil genesis. Its potential usefulness is derived from the fact that it offers the possibility of making predictions about soil-plant systems in situations which make it unrealistic to obtain data by direct measurement. The predictions are based on simulation of system processes rather than on statistical extrapolation. In this paper three examples are presented in which fairly realistic simulations of the effects of radioactive fallout and fertilization in soil-plant systems have been made. Finally, a proposal is made for an initial approach to the simulation of some aspects of soil formation. If adequate simulation models can be devised for soil formation or system perturbations, it opens the possibility for computer "gaming" exercises. Such exercises may make it possible to examine the effects of independent variables, such as climate and vegetation, on soil genesis in an experimental setting or to optimize management strategies in the use of fertilizers and pesticides in agriculture. (Auth.)
MODEL TYPE: parametric
COMMENT: Paper contains examples of systems analysis models relevant to assessment purposes.

<112>
Kraeger Rovey, C.E. 1975. Numerical model of flow in a stream-aquifer system. Hydrology papers No. 74, Colorado State University, Ft. Collins, CO.
ABSTRACT: A three-dimensional, finite difference model was developed for simulating steady and unsteady, saturated and unsaturated flow in a stream aquifer system. The basis of the model is the finite difference form of Richard's equation for unsaturated and saturated subsurface flow. Effects of streamflow on groundwater movement are treated by applying the appropriate boundary conditions to Richard's equation. Contributions of groundwater to river flow are quantified by including seepage rates in the computation of river discharge. The three-dimensional model was developed for use in this study to interact with two-dimensional model segments, which were interfaced with the three-dimensional model on its upstream and downstream ends. The model produced results which match observed data for the study area, which consisted of a 40 mile reach of the Arkansas Valley of Southeastern Colorado. Computed estimates of river discharge at each end of the study area and water table elevations throughout the region agreed reasonably well with observed data. An analysis of the sensitivity of results produced by the model to variation in the values of several input parameters was included as part of the study. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Detailed water flow model with potential use in assessment although detailed site data are required for inputs.

<113>
Larsen, R.I., and W.W. Heck. 1976. An air quality data analysis system for interrelating effects, standards, and needed source reductions: Part 3. Vegetation injury. J. Air Pollution Control Assoc. 26:325-333.
ABSTRACT: Acute leaf injury data are analyzed for 19 plant species exposed to ozone or sulfur dioxide. The data can be depicted by a new leaf injury mathematical model with two characteristics: (1) a constant percentage of leaf surface is injured by an air pollutant concentration that is inversely proportional to exposure duration raised to an exponent; (2) for a given exposure duration, the percent leaf injury as a function of pollutant concentration tends to fit a lognormal frequency distribution. Leaf injury as a function of laboratory exposure duration is modeled and compared with ambient air pollutant concentration measurements for various averaging times to determine which exposure durations are probably most important for setting ambient air quality standards to prevent or reduce visible leaf injury. The 8 hour average appears to be most important for most of the plants investigated for most sites, 1 hr concentrations are important for most plants at a few sites, and 3 hr SO(2) concentrations

APPENDIX A
Agricultural Models (continued)

<113> CONT.
are important for some plants, especially those exposed to isolated point sources of the pollutant. The 1, 3, and 8 hr threshold injury concentrations are listed for each of the 19 plant species studied. To prevent or reduce acute leaf injury, fixed, nonoverlapping ambient air quality measurements and standards are recommended for averaging times of 1, 3, and 8 hr. (Auth.)
MODEL TYPE: parametric
COMMENT: Useful empirical data source and representative function that can be used to predict visible plant response to air pollution.

<114>
Lavorel, J. 1976. Matrix analysis of the oxygen evolving system of photosynthesis. J. Theor. Biol. 57:171-185.
ABSTRACT: A linear four-step model is currently adopted to interpret the kinetic behaviour of the oxygen evolving system of higher plants' photosynthesis. Applying matrix analysis to this model allows one to derive three symmetrical functions of the transition probabilities of the model. It is shown that they constitute in general the only information concerning the model which can be extracted from experimental data. The analysis is applied to a series of published data. New properties of the oxygen evolving system are thus disclosed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Basic plant physiological model with no application in assessment.

<115>
Lettau, B. 1971. Determination of the thermal diffusivity in the upper layers of a natural ground cover. Soil Sci. 112:173-177.
ABSTRACT: It has been shown that the temperature variation in an inhomogeneous medium can be represented quite well by assuming that the vertical heat flux divergence which produces the local temperature change is composed of two terms: a classical term incorporating the curvature of the temperature profile, and a gradient term (here defined) incorporating the vertical variation of the thermal conductivity. Although the differential equation of temperature as a function of time may not be solved analytically, the temporal variation may be synthesized by numerical integration. The model has a direct physical interpretation and does not require the introduction of mathematical artifices such as a diurnally varying thermal diffusivity or a negative thermal diffusivity. The model furthermore accurately reproduces the ambient thermal processes, and the derived results are not ambiguous in the sense of parameters derived separately from the amplitude decrease and the phase lag of an applied surface temperature wave. (Auth.)
MODEL TYPE: mechanistic
COMMENT: The effects of waste heat on soil thermal properties could be evaluated with this model.

<116>
Lindstrom, M.J., R.I. Papendick, and F.E. Koehler. 1976. A model to predict winter wheat emergence as affected by soil temperature, water potential, and depth of planting. Agron. J. 68(1):137-141.
ABSTRACT: Establishment of adequate stands of winter wheat (TRITICUM AESTIVUM L.) in northwest USA is often hampered by low soil temperature or moisture, or by deep planting to reach moisture sufficient for emergence. Because of the wide variability and interactive effects among these factors, it is often difficult to predict the rate and extent of emergence of field plantings. A model was devised to predict emergence time of 'McCall' and 'Nugaines' winter wheat as a function of soil temperature between 5 and 25 C, water potential down to -10 bars, and planting depth. Predictions were reasonably good when compared with field measurements, particularly at high water potentials and with shallow planting. In general, the emergence rate progressively decreased with lowering of water potential, lowering of temperature from 25 C, or with increase in planting depth. The lower limit or minimum water potential for emergence increased with increasing temperature. Both wheats responded similarly to temperature decreases; however, the emergence rate of each variety responded differently to change in water potential. Differences in varietal response to water potential can possibly be characterized in terms of two parameters in the function describing the water potential effect on emergence. (Auth.)
MODEL TYPE: parametric
COMMENT: Model could be used to evaluate temperature effects on wheat emergence in northwestern USA.

<117>
Lungley, D.R. 1973. The growth of root systems - A numerical computer simulation model. Plant Soil 38(1):145-159.
ABSTRACT: A simulation model of the growth of the plant root system is described. Firstly, the numbers and lengths of the laterals derived from a single axis are obtained from specified rates of elongation and branching. Secondly, the vertical distribution of filament length is obtained, after specifying the rate of initiation of axes at the crown of the plant and the orientation of successive, short straight segments representing the curved roots. Diagrams of the network can be produced using the graph-plotting facility of computer, and other properties such as the distribution of length of filament of given age and the distribution of apices can be computed. The model has sufficient flexibility to incorporate information on the temporal variation or local spatial variation in rates of growth found under non-uniform conditions. The utility of the model in agronomic studies is illustrated by using it to calculate the effects of fertilizer treatments on the root distribution, given certain growth responses expressed in terms of rates of elongation and branching. The examples considered pertain to (a) the enrichment of a layer in the soil with a fertilizer supplying a scarce nutrient and (b) a deferred application of a fertilizer supplying a scarce nutrient. (Auth.)
MODEL TYPE: parametric
COMMENT: Could be adapted to evaluate pollutant effects on root development.

<118>
Lupton, F.G.H. 1972. Further experiments on photosynthesis and translocation in wheat. Ann. Appl. Biol. 71:69-79.
ABSTRACT: A model is developed relating photosynthesis taking place in successive layers of the canopy of a wheat crop to the intensity of the radiation incident on the crop, the elevation of the sun, and to the angle to the horizontal and photosynthetic area of ears, leaves and leaf sheaths. The validity of the model is tested by comparing the rate of photosynthesis, pattern of translocation and solid geometry of a semi-drawf wheat (TL 365a/25) with those of a

APPENDIX A
Agricultural Models (continued)

<118> CONT.
variety of conventional height (Cappelle-Desprez). The model gives realistic estimates of crop yield and indicates that the greater yield of the semi-dwarf selection is caused by faster photosynthesis, despite less photosynthetic surfaces of ears and leaves. It also indicates that selection for erect leaves may lead to further increases in yield. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Basic plant physiological model with no direct application in assessment studies.

<119>
Luxmoore, R.J., C.L. Begovich, and K.R. Dixon. 1978. Modelling solute uptake and incorporation into vegetation and litter. Ecol. Modelling 5:137-171.
ABSTRACT: The concepts and algorithms of the Baldwin, Nye and Tinker model describing solute movement from bulk soil solution into roots (DIFMAS) and a model of solute dynamics and accumulation in plant tissues and litter (DRYADS) are presented. Foliar uptake of solutes and gases are included in the DRYADS code. These models form components in a coupled system of models having hourly resolution of carbon, water, and solute dynamics in terrestrial ecosystems. Applications showing successive hourly, monthly, and annual results illustrate the utility of the models. The DRYADS model sensitive to both leaf solute conductivity and root solute conductivity parameters suggest the importance of careful experimental determination of these plant properties. The tissues of solute entry (leaves, roots) initially accumulate solutes in a fixed form in preference to the more remote tissues (stems, fruits). Model application results show that root sapwood is the first major site of trace contaminant accumulation from soil-borne pollutants. The algorithms describing solute movement along a concentration gradient in phloem and as mass flow in the xylem transpiration stream result in high mobility of solutes in vegetation. The simulated diurnal pattern of root solute uptake showed that more than 85% of solutes were taken up during the daylight hours. The simulations further showed that contaminants had the greatest efffect on the litter system. Toxic effects of contaminants on decomposition resulted in lower mineralization losses and accumulation of contaminant in litter with continuing deposition.
MODEL TYPE: mechanistic
COMMENT: Useful for simulation of particulate and gaseous pollutant transport and effects in soil-plant systems. Example of heavy metal and sulfur dioxide uptake given.

<120>
Luxmoore, R.J., J.L. Stolzy, and J.T. Holdeman. 1976. Some sensitivity analyses of an hourly soil-plant-water relations model. ORNL/TM-5343, Oak Ridge National Lab., TN.
ABSTRACT: Nineteen parameters representing landscape, plant, and soil characteristics were examined for their influence on midday plant water relations, daily fluxes and monthly water balance components predicted by a soil-plant-water relations model having hourly resolution. A standard set of parameters was chosen to represent a hardwood forest on ridge top soil in the Oak Ridge, Tennessee area during a representative summer month (July). Each parameter was varied through a range with all other parameters held at the standard value. The results of the study showed that the model was sensitive to nine plant parameters in noon, daily and monthly results. The ten other parameters had partial or no influence on the simulations. Two leaf characteristics and two landscape properties cause the model to be sensitive in midday values but less sensitive in monthly results due to the negative feedback aspects of the model. Five parameters had almost no influence on the model results in the case examined. The canopy interception parameter had almost no influence on the model results on sunny days, but was a significant component of the monthly water balance. The study highlighted the importance of the root and stem resistances to water flow in influencing plant water status and the monthly water balance. This study has provided an assessment of the model stability to wide ranges of parameter values and suggests the model's utility in a range of applications. These would include forest and agricultural crops on most soils and in diverse landscape situations. Further, the consequences of using parameters with high uncertainty in an application may be partially evaluated from these sensitivity tests. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Results from study could be used in assessment to evaluate possible effects of environmental changes on plant water relationships.

<121>
Luxmoore, R.J., L.H. Stolzy, and J. Letey. 1970. Oxygen diffusion in the soil-plant system. I. A model. Agron. J. 62:317-322.
ABSTRACT: A model for steady state, isothermal oxygen diffusion into a cylindrical root surrounded by a water film of uniform thickness is proposed. Equations are developed which account for longitudinal oxygen flux through the intercullular gas spaces, radial flux through the water film, and a respiratory oxygen sink which is defined as a function of oxygen concentration. A method of computer analysis is outlined whereby the law of continuity is applied sequentially to small sections of root, such that the amount of oxygen diffusing into a section is equated with the oxygen diffusing out plus the respiratory consumption. The solution for the model defines a series of oxygen concentrations along the root length. From these data the amount of oxygen consumed in respiration which diffuses into a top of the root (plant aeration) and the amount diffusing radially from the soil (soil aeration) may be calculated, and effects of soil and plant characteristics examined. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Any technology impact on plant or environmental properties used in the model could be evaluated. Model is mainly concerned with physiological research.

<122>
May, P.F., A.R. Till, and M.J. Cumming. 1972. Systems analysis of 35Sulphur kinetics in pastures grazed by sheep. J. Appl. Ecol. 9:25-49.
ABSTRACT: A mathematical model to represent the sulphur cycle in a grazed pasture was programmed on to an analog computer to simulate the results of a published field experiment in which observations were made on the incorporation of radioactivity into wool following a single application of [35S]gypsum to pasture. The behaviour of parts of the system not directly measurable and its responses to possible empirical manipulations were studied on the computer to suggest experimental tests of the model. The results of the study show that: (1) The observed

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Agricultural Models (continued)

<122> CONT.
transient behaviour of the specific activity of wool is consistent with a closed-system recycling process involving c. 60% of the total sulphur in the system. (2) Up to 90% of the cycling sulphur may be held in organic residues in forms not directly available to plants. (3) The rate of release of organic sulphur from these residues in forms suitable for plant uptake is a major determinant of the sulphur supply to plant and animal compartments of the system. (4) The productive potential of the system is in general determined by the rate of sulphur transport between compartments rather than the amount present in any compartment at any time. (Auth.)
MODEL TYPE: parametric
COMMENT: Very useful model for assessment of chemical transfer in plant-animal systems.

<123>
McCullough, E.C., and W.P. Porter. 1971. Computing clear day solar radiation spectra for the terrestrial ecological environment. Ecology 52:1008-1015.
ABSTRACT: Clear sky (cloud-free) horizontal plane terrestrial solar radiation spectral fluxes can be computed for any time of day and year, geographic location (latitude and longitude), and elevation upon inputting the optical properties of the atmosphere and reflecting properties of the underlying surface. Consideration is given to the problem of diffuse terrestrial radiation spectra for non-sea level elevations and where the terrestrial atmosphere cannot be regarded as being purely a Rayleigh atmosphere. Computation of terrestrial spectra for "large" zenith angles (Z greater than or equal to 72 deg.) is considered along with a discussion of irradiation patterns peculiar to polar zones (i.e., long days and nights). Selected results from the integration of these concepts into a computer program include the computation of total diffuse-to-direct flux ratios for radiation from a Rayleigh atmosphere at any solar zenith angle and selected elevations with typical mean ground albedos. Comparisons of integrated energy predictions with measurements in the literature agree favorably. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful in evaluation of spectral changes in irradiaton which could be induced by technology impacts on the optical properties of the atmosphere.

<124>
Miller, E.E., and J.M. Norman. 1971. A sunfleck theory for plant canopies, I. Lengths of sunlit segments along a transect. Agron. J. 63(1):735-738.
ABSTRACT: The size distribution of sunflecks under a plant canopy can be represented by the length distribution of sunlit segments along a straight-line transect drawn under the canopy. A mathematical connection is deduced between this sunlit-length distribution and the probability, as a function of length, that a short line placed randomly under the canopy will be everywhere in sunlight. In turn, this probability distribution is deduced for randomly-placed leaves, from which the above-mentioned connection yields the desired sunlit-length distribution. In subsequent papers this basic result will be used to predict the effect of penumbra - fuzzy shadow edges caused by the finite angular size of the sun - upon the light intensity distributions within or beneath canopies, as a function of leaf size, shape, height, density, and orientation. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Theoretical analysis that could have some assessment applications. However, in terms of photosynthesis prediction, the penumbra effects do not contribute significantly.

<125>
Miller, E.E., and J.M. Norman. 1971. A sunfleck theory for plant canopies, II. Penumbra effect: Intensity distributions along sunfleck segments. Agron. J. 63:739-743.
ABSTRACT: The finite (1/2 deg.) angular diameter of the sun causes the fuzziness of the shadow cast onto the ground by a leaf edge to increase in proportion to increase in height of the leaf. When a straight-line sunfleck segment is terminated by a leaf edge that cuts across it at a slant, the apparent width of the penumbral fringe displayed upon the segment is stretched by the slant. In this paper the intensity distribution along a slanting traverse of a penumbral shadow edge is computed, the statistical distributions of leaf-edge angles at the ends of segments are analyzed, and these two distributions are combined into a statistically-averaged intensity distribution along the segment, the distribution being dependent upon the segment length. When this intensity distribution is incorporated into the segment length distribution from the preceding paper of this series, a useful prediction is obtained for the complete distribution of intensity within a plant canopy. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Theoretical analysis that could have some assessment applications. However, in terms of photosynthesis prediction the penumbra effects do not contribute significantly.

<126>
Miller, E.L., and W.D. Shrader. 1976. Moisture conservation potential with conservation tillage treatments in the thick loess area of western Iowa. Agron. J. 68(2):374-378.
ABSTRACT: Moisture is usually in short supply for production of corn (ZEA MAYS L.) on thick loess derived soils in western Iowa. Practices that conserve moisture should increase crop yields but quantitative data is very scarse. The objectives were to develop a yield response curve for moisture applicable in western Iowa and evaluate the potential effect of conservation tillage systems on corn yields. Computerized modeling techniques were used to develop the yield response curve and to evaluate conservation practices. Moisture stress indices, which were highly correlated with measured corn yields, were used to evaluate the effectiveness of modeled tillage treatments in terms of corn yield. The model budgeted daily soil moisture use based on initial soil moisture measurements, actual weather data, and simulated hydrologic processes. The appropriate hydrologic processes were modified to approximate the tillage system under study. The hydrologic processes assumed most altered by conservation tillage management were surface runoff and surface evaporation in the spring fallow period. The modeled tillage practices were evaluated at three assumed spring soil moisture levels in combination with actual long term weather records. When spring soil moisture levels were at 100% of the plant-available water capacity (PAWC), tillage practices had little effect on estimated corn yields. At the medium and low spring soil moisture levels, modeled conservation tillage was effective in increasing yield estimates over those

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Agricultural Models (continued)

<126> CONT.
obtained with conventional tillage. (Auth.)
MODEL TYPE: parametric
COMMENT: Empirical model that could be adapted for assessment of technology impacts in western Iowa.

<127>
Miller, J.E., J. Hassett, D.E. Koeppe, G.L. Rolfe, and G.L. Wheeler. 1974. Effects of soil properties on Pb uptake by corn and effects of Pb and Cd on corn root elongation. In: T. Novakov (ed.), Trace contaminants in the environment, pp. 290-296. LBL-3217, Lawrence Berkeley Laboratory, Berkeley, CA, 365 pp.
ABSTRACT: The uptake of Pb into the shoots of six week-old corn plants was found to decrease with an increase in soil pH, cation exchange capacity (CEC), and available phosphorus. The Pb effects on growth of the corn plants were not as clearly related to these soil properties as was the uptake of Pb, although the greatest reduction of growth was seen in the low CEC and low pH soils. An experiment on corn root growth indicated that concentrations of Pb and Cd which by themselves would not inhibit root elongation did cause an inhibition when added together. A preliminary model of the Pb and Cd effects on root growth is presented. (Auth.)
MODEL TYPE: parametric
COMMENT: An exponential growth function with a growth rate parameter dependent on cadmium and lead concentration could be adapted for assessment purposes.

<128>
Miller, P.C., and W.A. Stoner. 1976. A model of stand photosynthesis for the wet meadow tundra at Barrow, Alaska. Ecology 57:411-430.
ABSTRACT: A model of radiation, air temperature, and vapor density in the vegetation canopy, plant water relations, and photosynthesis, developed in the primary production research program of the U.S. Tundra Biome, IBP, is described and results for the years 1970 through 1973 presented. The model calculates daily courses of direct and diffuse solar radiation; infrared radiation; wind; air temperature and humidity; leaf temperatures; convectional and transpirational exchange by leaves, stems, and dead material; leaf H(2)O content, leaf water potential; leaf resistance to H(2)O loss; internal resistance to CO(2) diffusion; and net photosynthesis. Climate varied from year to year: 1970 and 1971 were similar, 1972 was relatively warm and dry, and 1973 was relatively cold and wet. Plant parameters were obtained for CAREX AQUATILIS, DUPONTIA FISCHERI, ERIOPHORUM ANGUSTIFOLIUM, and SALIX PULCHRA. Leaf area indices varied by species and by year. Leaf areas of all species were lowest in 1973. Of the incoming solar radiation approximately 20% is reflected back and 32%-53% absorbed by the canopy, increasing with leaf area index. In the canopy 5-10 times more heat is lost by convection than by evaporation. Total seasonal vascular plant CO(2) uptake ranged from 400-627 g CO(2).m(G)**(-2) (subscript G refers to ground). In 1971 cuvette estimates for total seasonal vascular plant CO(2) uptake were 602 while the model predicted 627. Individual species incorporated about 4 g CO(2).m(G)**(-2).day(-1) at most. The daily CO(2) incorporation was larger than the downward CO(2) flux from the atmosphere, implying that soil respiration is a source of CO(2) for the vascular plants. Photosynthesis increased with solar radiation, air and ground temperatures, and air vapor density and decreased with increasing infrared radiation for the sky and root resistance to water uptake. Factors increasing transpiration without directly affecting photosynthesis tend to decrease photosynthesis because of the effect on water stress. Net photosynthesis is higher at the top of the canopy, in spite of more favorable temperatures within the canopy, because of light limitation. Total accumulted carbon dioxide, after subtracting growth costs of leaves, becomes positive late in the season and is highest at the lower levels because of the longer duration of leaf area at these levels. Photosynthesis seems adjusted to maximize carbon gain under the most frequent conditions but not under all conditions or extreme conditions. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Very useful model that could be applied in assessment of technology effects on crop water use and photosynthesis.

<129>
Molz, F.J., and I. Remson. 1970. Extraction term models of soil moisture use by transpiring plants. Water Resour. Res., 6(5):1346-1356.
ABSTRACT: A mathematical model is developed describing moisture removal from soil by the roots of transpiring plants. The model uses a macroscopic extraction term in the one-dimensional soil moisture flow equation. It describes both moisture removal by the plant and induced moisture movement through the soil. A numerical procedure based on the Douglas-Jones predictor-corrector method is used to solve the model, and solutions are compared with experimental data. The results indicate that extraction term models are computationally and physically feasible and give insight into the mechanics of the overall moisture extraction process. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Basic physiological model for understanding plant mechanisms. Not recommended for assessment.

<130>
Molz, F.J., and I. Remson. 1971. Application of an extraction-term model to the study of moisture flow to plant roots. Agron. J. 63:72-77.
ABSTRACT: A one-dimensional extraction-term model is used to simulate the moisture flow and removal process in the vicinity of plant roots. The dependence of model results on root depth and soil type are investigated. Moisture contents, root moisture absorption rates and soil-mositure fluxes are computed and discussed for several hypothetical root systems in a sandy soil and in a clay soil. The model is solved numerically with a procedure based on the Douglas-Jones predictor-corrector method. Results indicate that moisture extraction by the roots from soil in their immediate vicinity is the dominant process with Darcian flow in the root zone playing a smaller but often significant role. Extraction-term models are versatile and seem to describe many of the phenomena associated with moisture removal by the roots of transpiring plants. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological model that could be incorporated into a more comprehensive model of soil-plant water flow. As it stands the model has little direct application for assessment purposes.

<131>
Monteith, J.L. 1965. Light distribution and photosynthesis in field crops. Ann. Bot. NS 29:17-37.

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Agricultural Models (continued)

<131> CONT.
ABSTRACT: In a new model of light distribution in field crops, a parameter s is the fraction of light passing through unit leaf layer without interception. Radiation profiles measured with solarimeters and photocells give values of s from 0.7 for grasses to 0.4 for species with prostrate leaves. Knowing s, leaf transmission tau and leaf-area index L, the light distribution in a field crop may be described by a binomial expansion of the form (s+(I-s)tau)L. To calculate crop photosynthesis at given light intensity this expansion is combined with two parameters describing the shape of the light-response curve of single leaves. Finally, the assumption that solar radiation varies sinusoidally allows daily total photosynthesis to be estimated from daylength and insolation. The theory predicts about the same potential photosynthesis in a cloudy temperate climate with long days as in a more sunny equatorial climate with short days. When L <3, photosynthesis increases as s decreases, i.e. as leaves become more prostrate; but when L >5, photosynthesis increases as s increases, i.e. as leaves become more erect. Assuming that respiration is proportional to leaf area, estimated dry-matter production agrees well with field measurements on sugar-beet, sugar-cane, kale, and subterranean clover. Estimates of maximum gross photosynthesis (for sugar-cane and maize) range from 60 to 90 g/m**2/day depending on insolation. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Very useful model that has been incorporated into plant growth models. Could be applied to evaluate technology effects on the leaf overlap parameter S and canopy photosynthesis.

<132>
Murphy, B.D. 1976. The influence of ground cover on the dry deposition rate of gaseous materials. UCCND/CSD-19, Oak Ridge National Laboratory, Oak Ridge, TN 37748.
ABSTRACT: We discuss dry deposition rates for gaseous pollutants such as SO(2) on vegetated surfaces. From the discussion there follows a scheme for calculating deposition velocity. This scheme takes into account the equally important roles of aerodynamic and surface processes. In treating the surface-dependent part of the problem, we have identified those features which are of major importance and we discuss their parameterization. Results, derived for typical situations, show the manner in which the kind and condition of surface cover affects deposition rate. The concluding section points out the necessity for empirical validation, particularly for the case of forest cover. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful model for pollutant deposition onto vegetated surfaces.

<133>
Nakano, Y., and R.P. Murrmann. 1971. A statistical method for analysis of diffusion in soils. Soil Sci. Soc. Am. Proc. 35:397-402.
ABSTRACT: A special Monte Carlo method for use in investigating problems which involve random processes is developed. This approach differs from the usual Monte Carlo method for solution of differential equations in that the random process itself is constructed directly. The power of this approach is demonstrated by application of the method using two examples. In one case, the effect of thermal gradient on ionic diffusion through thin films of interfacial water in frozen clay is examined. The predicted ionic distribution is in agreement both with experimental data and with the result obtained by exact solution of the diffusion equation. In the second example, the distribution of acetone deposited in soil near the soil-atmosphere interface is calculated for a two-layer profile in which the adsorption coefficient and void-porosity vary between horizons. (Auth.)
MODEL TYPE: statistical
COMMENT: Research model that could be adapted to evaluate pollutant gas movement into soil.

<134>
NaNagara, T., R.E. Phillips, and J.E. Leggett. 1976. Diffusion and mass flow of nitrate-nitrogen into corn roots grown under field conditions. Agron. J. 68:67-72.
ABSTRACT: Nitrate-nitrogen, the most important source of N of non-leguminous plants, is soluble in soil water and is transported to plant roots by both mass flow and diffusion. It is, therefore, important to evaluate the relative importance of each of these two mechanisms of transport of NO(3)-N to plant roots and the environmental conditions under which each is the dominant mechanisms of transport. The objective of this paper was to present measurements of plant and soil parameters necessary for estimating accumulation of N grown under field conditions with the use of a theoretical model and to compare estimates of accumulation of N in the corn plant with measured accumulation in the plant. Plant and soil parameters were measured 37, 49, 76 and 97 days after planting on corn grown under field conditions for use in the theoretical model to predict uptake of N by the roots. The plant and soil parameters measured were volumetric soil water content, concentration of NO(3)-N in soil solution, porous diffusion coefficient of NO(3)-N in soil, average macroscopic velocity of soil water at plant root surface, radius of root, transpiration rate, and plant root length. In the derivation of the theoretical model it was assumed that the flux of NO(3)-N into the root was proportional to the concentration of NO(3)-N in the soil solution surrounding the root; the constant of proportionality, k, relating these two quantities has been referred to as the "absorbing power of the root." A linear relationship between flux and concentration was found to exist up to a concentration as high as 160 microgram NO(3)-N/cm**3 of soil solution for corn grown under field conditions. The proportionality constant, k, was found to decrease with time and/or age of the plant; k values of 0.51, 0.35 and 0.26 cm**2/sec were found for three harvest dates corresponding to 34 to 49, 49 to 76, and 76 to 97 days after planting, respectively. The errors of the predicted uptake of N as compared with measured accumulation were as large as 50% for the individual harvest periods. However, the error was greatly reduced when the predicted values and measured values were summed over the three harvest periods. In general, the predicted uptake values were smaller than the measured values when the measured values of accumulation were less than 1,200 mg of N/plant; the reverse was true when the measured values of accumulation were greater than 1,200 mg of N. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Set of parameter values determined for corn could be used in assessment applications.

<135>
Nimah, M.N., and R.J. Hanks. 1973. Model for estimating soil water, plant, and atmospheric interrelations, I. Description and

APPENDIX A
Agricultural Models (continued)

<135> CONT.
sensitivity. Soil Sci. Soc. Am. Proc. 37:522-527.
ABSTRACT: A model and its numerical solution were developed to predict water content profiles, evapotranspiration, water flow from or to the water table, root extraction, and root water potential under transient field conditions. Soil properties needed are hydraulic conductivity and soil water potential as functions of water content. Plant properties needed are rooting depth and limiting root water potential. Climatic properties needed are potential evaporation and potential transpiration. The model predicted significant changes in root extraction, evapotranspiration, and drainage due to the variations in pressure head-water content relations and root depth. Variations in the limiting root water potential had a small influence on estimated evapotranspiration, drainage, and root extraction. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model does not allow different soil hydraulic properties for layered soils and has limited flexibility.

<136>
Nimah, M.N., and R.J. Hanks. 1973. Model for estimating soil water, plant, and atmospheric interrelations, II. Field test of model. Soil Sci. Soc. Am. Proc. 37:528-532.
ABSTRACT: A mathematical model was developed to predict water content profiles, evapotranspiration, water flow from or to the water table, root extraction, and root water potential at the surface under transient conditions. The model was field tested in 1970 and 1971. With alfalfa (MEDICAGO SATIVA L.) as the crop, predicted and computed water content-depth profiles show best agreement 48 hours after any water addition. The poorest agreement for all crops tested was right after irrigation. The computed cumulative upward water flow from the water table was 4.80 cm as compared to 0.0 cm measured for the whole 1971 season of 116 days. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful data source for assessment applications involving alfalfa on sandy loam soils.

<137>
Norman, J.M., E.E. Miller, and C.B. Tanner. 1971. Light intensity and sunfleck-size distributions in plant canopies. Agron. J. 63:743-748.
ABSTRACT: A theory predicting the gap-size distribution of a canopy of horizontal, azimuthally symmetric, randomly located, flat leaves of any shape is compared to measurements in sumac (RHUS TYPHINA L.), sunflower (HELIANTHUS ANNUUS L.), and an artificial canopy. Light intensity distributions of the solar beam component on a horizontal surface below these canopies are predicted by combining the gap-size distribution theory with penumbral effects of the finite solar disc. These predictions of the beam-component distribution are then combined with average diffuse penetration theory and a new scattering theory to produce a final light intensity distribution for comparison with measurements from a miniature light sensor in visible and near-infrared wavelength bands. The agreement is good and indicates that sizable penumbra effects occur in canopies only 2 m in height. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Provides physical relationships that could be included in whole plant models. This detail is probably not needed in assessment applications.

<138>
O'Connor, G.A., M.T. van Genuchten, and P.J. Wierenga. 1976. Predicting 2,4,5-T movement in soil columns. J. Environ. Qual. 5:375-378.
ABSTRACT: A solute model developed by van Genuchten and Wierenga was used to calculate 2,4,5-T effluent data from soil columns. The model had been previously shown to adequately predict effluent data given model parameters curve fit to a portion of the effluent curve. The present work shows that 2,4,5-T effluent curves may be adequately predicted without prior knowledge of the effluent curves for a particular soil column given: (i) model parameters derived from 2,4,5-T effluent curves for other soil columns, or (ii) model parameters obtained from tritium effluent curves for the same columns. The data suggest that once the physical model parameters have been characterized for a soil, reasonable predictions of 2,4,5-T (and perhaps other solutes) transport can be made given the adsorption coefficient for the solute. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Useful for simulation of chemical movement through soil columns, but cannot be relied upon for field chemical behavior.

<139>
O'Gara, P.J. 1922. Sulfur dioxide and fume problems and their solutions. J. Ind. Eng. Chem. 14:744.
ABSTRACT: A seven year study of SO(2) effects on the growth of about 200 plant species under varying field conditions of light, temperature, humidity and stage of growth has resulted in the discovery of "the law of gas action on the plant cell." This law states that with all environmental factors remaining the same, the active part of a gas necessary to produce a certain effect on the plant cell, multiplied by the time through which it acts, is constant.
MODEL TYPE: parametric
COMMENT: This law has been used extensively to represent pollutant effects.

<140>
O'Neill, R.V., and O.W. Burke. 1971. A simple systems model for DDT and DDE movement in the human foodchain. ORNL-IBP-71-9, Oak Ridge National Lab., Oak Ridge, TN.
ABSTRACT: This report documents a model of DDT and DDE movement in human foodchains. The model was developed from data supplied by the Advisory Committee on DDT, Environmental Protection Agency and attempts to forecast pesticide concentrations in man under alternative assumptions about DDT application in the United States. (Auth.)
MODEL TYPE: parametric
COMMENT: The method could be adapted to assessment of energy technology impacts.

<141>
Osman, A.M. 1971. Dry-matter production of a wheat crop in relation to light interception and photosynthetic capacity of leaves. Ann. Bot. 35:1017-1035.
ABSTRACT: In a wheat crop in the field, the relationship between leaf-area index and the transmission of visible, infra-red, and total radiation was found to be close to Beer's law; however, there was an indication of curvilinearity in the visible radiation profile at the bottom layers of a dense crop. The extinction coefficient for visible, infra-red, and total radiation was found to vary with time in a less dense crop. s(v) the fraction of visible radiation that passes

APPENDIX A
Agricultural Models (continued)

<141> CONT.
through unit leaf layer without interception, was found to increase with increase in the leaf-area index of the two crops. The Monteith model was used to calculate the gross photosynthesis of leaves. The contribution by stems and ears and the respiration losses of all organs of the plant were taken into account when calculating the dry-weight increases and the importance of their variation was assessed. A satisfactory agreement between the estimated and measured increases was found. The significance of variation in the extinction coefficients and s(v) on gross photosynthesis of leaves was explored. The variation in the visible radiation-response curves of different leaves was found to have a large effect on the gross photosynthesis of leaves. The total respiration of the mass of leaves in the canopy was found to be of great significance in dry-weight increases. A general dependence of the dry-matter production of the amount of total incoming visible radiation was found. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This is an application of the Monteith (1965) model.

<142>
Page, E.R., and A. Gerwitz. 1974. Mathematical models, based on diffusion equations, to describe root systems of isolated plants, row crops, and swards. Plant Soil 41:243-254.
ABSTRACT: Mathematical models to describe the density of plant roots in the soil have been developed by analogy from the equations describing diffusion or heat flow. Results from an experiment with isolated plants (lettuces) shows that the equation for diffusion from a point source applies, while results from a row crop (onions) indicate that when allowance is made for the assymetry resulting from a preferred direction of growth, the equation describing diffusion from a line into a semi-infinite medium can be applied. Results reported by other workers for ryegrass are used to demonstrate that for a sward the appropriate equation is that describing diffusion from a plane into a semi-infinite medium. (Auth.)
MODEL TYPE: parametric
COMMENT: Model is not directly applicable in assessment.

<143>
Paltridge, G.W. 1970. A model of a growing pasture. Agric. Meteorol. 7:93-130.
ABSTRACT: An attempt is made to model a developing pasture in a manner requiring no experimental data on dependent variables. The term "pasture" here includes all forms of uniform vegetation which can be characterized primarily by leaves and roots. The model is based on the concept of limiting values. At any time at a particular level in the canopy, growth is determined by one of three parameters (radiation available, carbon dioxide available, or the capacity of individual leaves to carry out the photosynthetic conversion) which are calculable from the defined above-crop external conditions and the parameters of the plant which have been selected as independent. Because the model does not rely on field data, it is possible to use simple evolutionary constraints to enable the pasture to generate its own architecture as the photosynthesized material becomes available. Soil water status is included, so that the effect of water deficit on the growth pattern of both leaves and roots can be investigated. The trials of the model so far have not been true simulations in the sense that the leaves and roots have been identified with a particular crop. However, the most obviously useful agrometeorological concepts have been incorporated, so that for a particular simulation attempt it is only necessary to devise suitable physical descriptions of leaf shape and orientation which at the same time enable calculation of the necessary dependent variables (for instance, the vertical mass transfer coefficient and the radiation flux). Illustrative trials of the model compare well (in those aspects where comparison is possible without direct simulation) with real pastures, and reveal behaviour-patterns which may help to direct experimental research in the field. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Research model addressing physiological questions and not suitable for assessment.

<144>
Paltridge, G.W., and J.V. Denholm. 1974. Plant yield and the switch from vegetative to reproductive growth. J. Theor. Biol. 44:23-34.
ABSTRACT: Many plants have a fairly sharp division between their vegetative and reproductive phases of growth. Switch-over does not necessarily occur at the optimum time, and the resultant drop in yield may be essentially independent of any variation in basic photosynthetic ability. If this is so, it may be necessary to compare the measured yield in any agricultural trial with the equivalent optimum yield for the particular crop. A basic mathematical model of a two-phase system is developed which involves the rates of growth of green material and grain, and takes leaf senescence and the effect of the environment on photosynthesis into account. The application of the model is discussed by reference to a well-documented wheat crop. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model designed to examine physiological questions and not suitable for assessment.

<145>
Parkhurst, D.F., P.R. Duncan, D.M. Gates, and F. Kreith. 1968. Wind-tunnel modelling of convection of heat between air and broad leaves of plants. Agric. Meteorol. 5:33-47.
ABSTRACT: A method is described for calculating convection coefficients for thin broad leaves of arbitrary shape, using existing equations for rectangular flat plates. Electrically-heated models placed in a wind tunnel provide experimental support for the method. Effective dimensions for several real and idealized leaf shapes are presented. Experimental data from long, narrow leaf models show that convection in flow perpendicular to the leaf surface may be almost double the value for parallel flow. Three examples are discussed. (Auth.)
MODEL TYPE: parametric
COMMENT: Useful method to include in models of plant-physical environment interactions.

<146>
Passioura, J.B. 1963. A mathematical model for the uptake of ions from the soil solution. Plant Soil 18:225-238.
ABSTRACT: A model is developed in which the uptake of ions which exist wholly in the soil solution is described in terms of their net movement towards the surfaces of roots. The ions are assumed to move either by diffusion, or in the mass flow of water towards the roots, and, given these two ways of movement, the model is based on five main assumptions. The validity of these assumptions is

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Agricultural Models (continued)

<146> CONT.
discussed, together with some of the model's implications, and a few experiments are suggested by which it could be tested. (Auth.)
MODEL TYPE: mechanistic
COMMENT: An early model for solute uptake that has been superceded by later developments, eg. Balwin Nye and Tinker (1973).

<147>
Patefield, W.M., and R.B. Austin. 1971. A model for the simulation of the growth of BETA VULGARIS L. Ann. Bot. 35:1227-1250.
ABSTRACT: A simple explanatory model for the simulation of the growth of BETA is described. It takes account of photosynthesis, respiration, and the light-intercepting properties of the foliage, but uses the observed distribution pattern of dry matter. A crop of BETA was grown and, by periodic sampling of plants, growth curves were obtained. These are compared with simulated growth curves and the reasons for the discrepancies are discussed. From simulations with different values of the constants of the model, the effects on yield of variations in these constants are predicted. (Auth.)
MODEL TYPE: parametric
COMMENT: Model could be adapted for assessment of impacts on sugar beet crops.

<148>
Penning de Vries, F.W.T. 1972. A model for simulating transpiration of leaves with special attention to stomatal functioning. J. Appl. Ecol. 9:57-77.
ABSTRACT: A dynamic model of a water-containing and water-conducting system is described, representing a non-growing, transpiring leaf with an attached root in a nutrient solution. The simulated transpiration rate is determined by environmental conditions and leaf conductivity, the latter being mainly under stomatal control. A hypothesis of stomatal functioning based upon the interation between guard cells and subsidiary cells is presented. The control mechanism of the guard cells is supposed to be affected both by present and past plant water status, light intensity and CO(2) concentration in the leaf, which depends on photosynthesis and diffusion rates. The functon of subsidiary cells is taken to be affected only by present and past plant water status. Experiments are simulated to evaluate the model. The model is written in the computer simulation language CSMP and is presented in such a way that the added listing of it may be understood after studying this paper without previous knowledge of programming. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Similar models are available. This work is oriented to physiological research rather than assessment but could be adapted to evaluate some technology impacts.

<149>
Rai, D., and W.L. Lindsay. 1975. A thermodynamic model for predicting the formation, stability, and weathering of common soil minerals. Soil Sci. Soc. Am. Proc. 39:991-996.
ABSTRACT: Numerous workers have examined the weathering products of soil minerals and have proposed empirical weathering sequences. The present paper outlines the development of a thermodynamic model that predicts in a systematic way several mineral transformations that can occur in soils. According to this model, the stability of primary minerals increases in the order: Na-glass, K-glass, pyroxene, analcime, anorthite, low albite, muscovite, microcline, and quartz. The stability of secondary clay minerals depends on soluble silica. At pH 6 with high silica (nearly equals 10**(-3)M) the order of increasing stability is: chlorite, halloysite, gibbsite, illite, dickite, beidellite, kaolinite, and montmorillonite; at low silica (nearly equal 10**(-5)M) the order is: chlorite, halloysite, illite, beidellite, montmorillonite, dickite, kaolinite, and gibbsite. The stability of both primary and secondary minerals increases with pH. The observed weathering of volcanic ash agrees well with the predictions of this model. The model makes use of important thermodynamic data accumulated for soil minerals and helps to pinpoint deficiencies in these data. The need to examine the kinetics of mineral transformations in soils in greater detail also becomes obvious from this model. (Auth.)
MODEL TYPE: mechanistic
COMMENT: The Al-Si diagrams predicting mineral formation may be useful in evaluation of acid rain and/or pollutant effects on soil mineralogy.

<150>
Reed, K.L., and R.H. Waring. 1974. Coupling of environment to plant response: A simulation model of transpiration. Ecology 55:62-72.
ABSTRACT: A low-resolution simulation model of transpiration was developed and run, with data from field studies in southwestern Oregon. The output of the model served as a means of relating environmental variables to plant response. This relation was used to define an ordinate which, in conjunction with previously developed ecosystem ordinates, proved helpful for comparing ecosystems, predicting community composition and, in special cases, growth. The data requirements of the model are modest; we deliberately developed a model that can be used on data obtained from field studies where electric power is unavailable and use of sophisticated instrumentation is impossible. The model requires inputs of air and soil temperature, atmospheric humidity, seasonal plant water potential (expressed as plant moisture stress, the absolute value of plant water potential), and a model of stomatal behavior. Where it was impossible to obtain accurate data, stochastic models were used to provide the necessary input. The model simulated both potential and actual transpiration, the ratio of which is the most valuable single index of the seasonal moisture regime. Where no measurable stomatal control was exerted by Douglas-fir, the ratio was 1.0, indicating that adequate water was available to meet the transpiration demand. The ratio approached 0.3 on the drier locations. Significant changes in vegetation and growth were associated with this index. (Auth.)
MODEL TYPE: parametric
COMMENT: Could be useful in assessment where limited data are available.

<151>
Reiners, W.A. 1968. Carbon dioxide evolution from the floor of three Minnesota forests. Ecology 49:471-483.
ABSTRACT: Carbon dioxide evolution rates from forest floors, measured approximately weekly for 54 weeks in oak forest, marginal fern, and cedar swamp, were closely related to soil temperature and secondarily to moisture conditions. As a result, microclimatic and drainage characteristics of the three forests produced seasonal differences in carbon release. However, compensatory factors produced nearly equal cumulative annual

APPENDIX A
Agricultural Models (continued)

<151> CONT.
totals of CO(2) evolution. Total CO(2) evolution was over three times higher than expected from an equivalent amount of carbon release from annual litter fall. Respiration by tree roots was suspected as the major contributor to this disparity although methodological problems related to flow rate are still open to question. (Auth.)
MODEL TYPE: regression
COMMENT: Regression function could be used in a carbon budget model.

<152>
Ritchie, J.T. 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resour. Res. 8:1204-1213.
ABSTRACT: A model is presented for calculating the daily evaporation rate from a crop surface. It applies to a row crop canopy situation in which the soil water supply to the plant roots is not limited and the crop has not come into an advanced stage of maturation or senescence. The crop evaporation rate is calculated by adding the soil surface and plant surface components (each of these requiring daily numbers for the leaf area index), the potential evaporation, the rainfall, and the net radiation above the canopy. The evaporation from the soil surface E(S), is calculated in two stages: (1) the constant rate stage in which E(S) is limited only by the supply of energy to the surface and (2) the falling rate stage in which water movement to the evaporating sites near the surface is controlled by the hydraulic properties of the soil. The evaporation from the plant surfaces E(p) is predicted by using an empirical relation based on local data, which shows how E(p) is related to E(o) through the leaf area index. The model was used to obtain the total evaporation rate E=E(S)+E(p) of a developing grain sorghum (SORGHUM BICOLOR L.) canopy in central Texas. The results agreed well with values for E measured directly with a weighing lysimeter. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Very useful model for assessment of agricultural impacts.

<153>
Rogowski, A.S. 1971. Watershed physics: Model of the soil moisture characteristic. Water Resour. Res. 7:1575-1582.
ABSTRACT: The procedure is proposed by which reasonable estimates of the soil moisture characteristic can be obtained when a reliable curve is not available. Moisture content and pressure at air entry and at 15 bars constitute the required input parameters. The parameters are easily determined and at times can be readily abstracted from literature or estimated from published data. Applicability of the model is tested on graded sand and eight soils. (Auth.)
MODEL TYPE: parametric
COMMENT: Useful method for representation of soil hydraulic properties required in soil water flow models.

<154>
Rogowski, A.S. 1972. Estimation of the soil moisture characteristic and hydraulic conductivity: Comparison of models. Soil Sci. 114:423-429.
ABSTRACT: Three ways of modeling the moisture characteristic and two ways of modeling hydraulic conductivity of soils are described and compared. It is concluded that a modified Brooks and Corey conductivity model (LBC), and the moisture characteristic associated with it are quite similar in form to a modified (ASR) pore-size interaction model of Green and Corey. The results from both compare well with experimental values at higher moisture contents. However, the ASR model approximates the experimental results better at lower values of water content and over a wide moisture range. The moisture content and pressure at air entry appear to be significant parameters of the soil water system. A linear model of the soil moisture characteristic underestimates experimental results when used as input into the modified pore-size interaction model of hydraulic conductivity. (Auth.)
MODEL TYPE: parametric
COMMENT: Useful comparison of methods for calculating soil hydraulic properties which are needed in models of soil water flow.

<155>
Romkens, M.J.M., and R.D. Miller. 1971. Predicting root size and frequency from one-dimensional consolidation data - A mathematical model. Plant Soil 35:237-248.
ABSTRACT: An implicit relationship between root size and soil reaction to root growth pressure is developed for a cohesionless soil from data of one-dimensional consolidation tests. The mathematical model employed describes a phenomenological procedure of relating root size and root frequency to soil mechanical parameters. The model is based on: (1) a simplificaton of the observed dependency of void ratio on compression pressure, and (2) the assumption of an inverse relationship over the domain of root influence between the radial stress and the distance from the axis of the root. As radial expansion of a root proceeds, three successive and mathematically distinct stages of root growth are recognized in a preconsolidated soil. Relationships between root growth pressure and root size were computed for various combinations of bulk density, preconsolidation pressure, and values of the compression index in and beyond the range of preconsolidation. Root frequencies were calculated for a number of hypothetical situations assuming a hexagonal network of evenly distributed roots. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be used to evaluate changes in soil strength or compression effects on root growth.

<156>
Runge, E.C.A. 1973. Soil development sequences and energy models. Soil Sci. 115:183-193.
ABSTRACT: The importance of having an a priori model to guide our imaginative thoughts and research is desirable in any discipline. This is particularly important in a slowly changing system under continuous development such as soils where the separation of cause and effect is most difficult. A model of soil development based on energy vectors operative in soils is presented and discussed. The model proposed is simple initially but can become as complex as the situation requires. The model discussed may enable one to design experiments which have a higher probability of definitive results than do previous models. Also the model seems to allow for easier extrapolation of results. Hopefully the proposed model will help in predicting more accurately the effect of man's activity on soils of the world. (Auth.)
MODEL TYPE: conceptual
COMMENT: Could be useful in assessment to establish qualitative changes in soils induced by technology impact.

APPENDIX A
Agricultural Models (continued)

<157>
Russell, J.S. 1976. Comparative salt tolerance of some tropical and temperate legumes and tropical grasses. Aust. J. Exptl. Agric. Anim. Husb. 16:103-109.
ABSTRACT: The dry matter yield of 11 tropical legumes, 10 temperate legumes and 11 tropical grasses was examined in pot experiments on a clay soil with increasing levels of sodium chloride. A mathematical model was fitted to the yield-salt level curves for each species and both the half yield soil salinity level and zero yield soil salinity level were estimated. Species were ranked in relation to their salt tolerance at half and zero yield and these values were expressed in terms of the electrical conductivity of the soil saturation extract. Grasses showed a greater ability to persist at high salt levels than the legumes. The most tolerant grasses were CHLORIS GAYANA, PANICUM COLOATUM, PENNISETUM CLANDESTINUM, SORGHUM ALBUM and DIGITARIA DECUMBENS. MEDICAGO SATIVA, which was included in both temperate and tropical groups, was the most tolerant legume of both groups. The tropical legumes MACROPTILIUM LATHYROIDES and MACROPTILIUM ATROPURPUREUM were almost equivalent to M. SATIVA in their salt tolerance. The least tolerant grass was SETARIA ANCEPS and the least tolerant tropical and temperate legumes were DESMODIUM UNCINATUM and TRIFOLIUM SEMIPILOSUM, respectively. Both Na and Cl percentages in the plant generally increased with increasing salt but no consistent relationship was found between plant salt tolerance and Na and Cl content. The field implications of the high salt tolerance of certain grasses is discussed in relation to the establishment of permanent grass-legume pastures on saline-sodic soils. (Auth.)
MODEL TYPE: parametric
COMMENT: Simple and useful approach to evaluate salinity hazard.

<158>
Ryan, J.W., F.A. Garza, and S.L. Brown. 1974. A damage assessment model for agricultural crops. SRI-EGU-2729 Stanford Research Institute, Menlo Park, CA 94025.
ABSTRACT: This report describes the main feature of a model developed for the assessment of radiation damage to ten agricultural crops and the FORTRAN computer program that implements the crop assessment model. The ten crops included in the model were corn, sorghum, soybeans, rye, rice, potatoes, alfalfa, sugar beets, wheat, and barley. The objective of the research was to incorporate current research results into a model and program for the joint use of the Defense Civil Preparedness Agency, the U.S. Department of Agriculture, and the Office of Preparedness. The crop assessment model has three main submodels: (1) A crop morphology submodel that estimates the growth parameters of each crop at a resource location on the attack date. (2) A radiation dose submodel that uses the attack effects to estimate the total absorbed dose and effective dose rate for each crop in the county under consideration. (3) A crop survival submodel that estimates the crop yield surviving, based on the dose and dose rate and the growth stage of the plant. The major inputs required are crop growth parameters, planting and harvesting dates, and attack data describing the radiation levels. The model uses these inputs to calculate the percentage of yield surviving the attack effects. The model inputs and outputs and FORTRAN program were designed to be compatible with the READY program of the Mathematics and Computation Laboratory of the General Services Administration. The use of the crop assessment program and the results of a sample run are described in the last section of the report. The sample run was intended to provide to potential users a means of checking the implementation of the program on other computer systems. The sample output is also useful for demonstrating differences in crop survival over the various growth stages. (Auth.)
MODEL TYPE: parametric
COMMENT: Model is applicable to radiological assessment and can be used for these purposes.

<159>
Saeki, T. 1960. Interrelationships between leaf amount, light distribution and total photosynthesis in a plant community. Bot. Mag. 73:55-63.
ABSTRACT: In order to find a practical means of estimation of the production of matter in a plant community and to give a logical explanation to the variability of directly measured values, theoretical analyses have been advanced of the interrelationships between leaf amount, light distribution and total foliage photosynthesis. Inside foliage relative light intensity received by the leaves is not always the same as the light intensity measured at horizontal plane at the same height. In homogeneous stands the former can be derived from Equation (3), when leaf transmissibility is known and extinction coefficient (K in Equation (2)) is obtained beforehand by 'stratifying clip method'. If photosynthetic capacity in the active leaf and mean respiration rate of all the leaves in a stand are known, the mean total daily photosynthesis of whole foliage is estimated by Equation (5). An example in representative herbaceous species is presented, where it is clearly indicated that with lower 'leaf area index' daily production in foliage is indifferent to inclination of leaves, while with increase of leaf amount the role of inclination in the production becomes very remarkable, upright leaves being more efficient than horizontal ones under full daylight as demonstrated by Watson and Witts. Compensation light intensity and 'optimum leaf-area index' (leaf amount in the form of LAI for the highest production) are calculated from the photosynthetic capacity in the active leaf and respiration rate of the lower leaf (Equations (6) and (7)). The obtained values seem to be quite reasonable in consideration of the minimum light intensities and 'leaf area indexes' in the natural communities. The highest daily production in a plant community, P(max), calculated with Equation (8) was discussed in relation to the extinction coefficient and incoming radiation. An approximate coincidence was recognized between the calculated values and the highest net production in crop fields collated by Blackman and Black. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Early model for crop photosynthesis often used in more recent crop simulation models. Useful for assessment although more comprehensive models are available.

<160>
Sauer, R.H. 1976. The relationship of cumulative sums and moving averages of temperature to reproductive phenology in CLARKIA. Am. Midl. Nat. 95:148-158.
ABSTRACT: Flowering time (anthesis) differs among populations in the CLARKIA UNGUICULATA complex, and these differences appear to be adaptive with respect to avoiding the severe summer drought of the native habitats. As habitat elevation decreases, flowering time and soil drying occur earlier. Six

APPENDIX A
Agricultural Models (continued)

<160> CONT.
populations of the C. UNGUICULATA complex were grown in four temperatures to asess the effect of temperatue on the timing of five developmental stages (phenophases). Regressions were calculated using the days from planting to a given phenophase (age) as the dependent variable, and values of 126 combinations of moving average lengths, cumulative sums, threshold temperatures and daily air temperature maxima, minima and means when the various phenophases occurred as the independent variables. The timing of all phenophases were significantly correlated more often with moving averages than with cumulative sums, and it took longer to reach a given phenophase at the lower temperatures. The absence of interpopulation and interphenophase differences suggests that the temperature environments of the native habitats during flowering are similar and that observed differences in flowering time in uniform culture are the result of different responses to other environmental factors such as insolation and soil water potential. Flowering and habitat characteristics are combined into a graphic model that illustrates the importance of flowering in response to temperature to avoid summer drought. (Auth.)
MODEL TYPE: statistical
COMMENT: Could be used in assessment of climate change on plant phenology.

<161>
Schuepp, P.H., and K.D. White. 1975. Transfer processes in vegetation by electrochemical analog. Bound.-Layer Meteorol. 8:335-358.
ABSTRACT: Electrochemical modelling may provide fast order-of-magnitude estimates of energy and mass transfer in crops and partly fill the gap between rigid, expensive field experiments and oversimplified mathematical modelling. The technique comprises breaking up a flowing electrolyte in a manner analogous - but not necessarily completely similar - to the way the atmospheric flow is broken up by crops and studying the flow of ions in the electrolyte. The effects of variations in free-flow velocity, plant spacing, row spacing and orientation on velocity field, transfer coefficients and eddy diffusivities have been studied in an electrochemical model under conditions relevant to well-ventilated crops with relatively simple canopy structure. A one-dimensional analytical model is developed for the transfer at solid surfaces, with direct proportionality between transfer coefficient and eddy diffusivity. The proportionality constant alpha has values in the model of (3.5 plus or minus 0.5)x10**(-3)/cm at the ground and (5 plus or minus 2)x10**(-4)/cm (for a cylindrical probe) near canopy top. The latter is not too different from the values proposed for foliage surfaces in real canopies, viz., approximately 1x10**(-3)/cm (Philip, 1964) and 7x10**(-4)/cm (Uchijima, 1966). Alpha may therefore become a useful parameter in scaling transfer coefficients from systems with different molecular diffusion properties. A tentative extrapolation of measured data to corresponding values in air is given. The agreement between predicted values and presently available field data is encouraging although more precise field data are required for a final judgement on the validity of the model. (Auth.)
MODEL TYPE: electochemical analog
COMMENT: Experimental method of analog modeling that could be usefully applied in assessment if facilities were available.

<162>
Scott, B.I.H., and M.F. Gulline. 1972. Natural and forced circadian oscillations in the leaf of TRIFOLIUM REPENS. Aust. J. Biol. Sci. 25:61-76.
ABSTRACT: The leaves of white clover (T. REPENS) exhibit typical circadian characteristics with an endogenous period, tau, of 25-27 hr. Corresponding oscillations are observed of the torque exerted by leaflets prevented from closing. The mean variation in torque during a cycle was 339 plus or minus 13 dyne cm. When leaves were subjected to light-dark cycles at constant temperature, entrainment was obtained for periods from 0.7 to 1.4 tau. Phase shifts were observed ranging from a lag of 40 deg. for 0.7 tau to an advance of 130 deg. for 1.4 tau. The pulvinus was shown to be both the photoreceptor and the site of the endogenous timer. Similar responses to those for light were observed in leaves under constant illumination which experienced rhythmic temperature variations between 8 and 18 deg. C, and between 15 and 22 deg. C. A mathematical model is considered of a simple oscillatory systems whose natural oscillations and phase responses to forcing oscillations resemble those of the leaf. It is argued that the basic oscillator is linear, producing damped sinusoidal oscillations, and that the non-linearities which introduce higher harmonies in the observed leaf oscillation occur in the coupling between oscillator and output.
MODEL TYPE: parametric
COMMENT: Probably not useful in assessment.

<163>
Scrivner, C.L., J.C. Baker, and D.R. Brees. 1973. Combined daily climatic data and dilute solution chemistry in studies of soil profile formation. Soil Sci. 115:213-223.
ABSTRACT: A model was developed for converting long-time daily records of temperature and precipitation into daily depths of moistening and drying of the soil. The time-depth distributions of moist and dry zones were summed and converted to a prediction equation of the form, log F=k(1)-k(2)*log D where F is the frequency of completed moist-dry cycles; D is depth, and k(1) and k(2) are constants characteristic of a particular soil and climate. The average annual amount of excess precipitaion that fell when soil moisture was completely recharged completed the numerical description of the soil moisture regime. The depth that has a frequency of one completed moist-dry cycle per year coincides with the depth of solum in Missouri soils. It appears that the upper boundary of the B horizon is determined by the average depth of penetration of summer rains. Estimated amounts of water passing planes in the soil can be summed by integration of the prediction equation for depth-frequency of completed moist-dry cycles. Analyses of soil solutions produced when dry soil samples were equilibrated with water for one week suggest that alumino-sulicate minerals react in a manner that is predicted by chemical thermodynamics. Kaolinite appears to be the stable clay mineral in a wide array of soil horizons including those with large amounts of montmorillonite. Quartz appears to be instable in some A horizons, in layers adjacent to limestone and in all horizons of a gibbsitic soil containing quartz. (Auth.)
MODEL TYPE: regression
COMMENT: Simple model that could evaluate climate change effects on soil profile formation.

<164>
Seginer, I. 1970. A resistance model of

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<164> CONT.
evaporation during sprinkling. Agric. Meteorol. 7:487-497.
ABSTRACT: A previous resistance model of sprinkler evaporation is expanded by considering two energy balance equations: one for the drops and another for the air layer where the evaporation takes place. To solve for the various fluxes, only the boundary conditions and the resistances of the system must be given. A comparison of calculations with experimental results, indicates good agreement for the limiting case of a wet surface with no drops in the air. The model predicts small spray evaporation under normal operating conditions. The effects of water temperature, fineness of spray and application rate on the evaporation losses may be significant, if the variation of any of these parameters is within wide limits. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used in technology impact assessment of cooling towers.

<165>
Shawcroft, R.W., E.R. Lemon, L.H. Allen, D.W. Stewart, and S.E. Jensen. 1974. The soil-plant-atmosphere model and some of its predictions. Agric. Meteorol. 14:287-307.
ABSTRACT: A general description of the soil-plant-atmosphere model (SPAM) is given. Emphasis is made as to the logical sequence of the operation of the model by use of various submodels depicting the soil, plant, and climatic interactions. Examples of the testing of the model are discussed. Some simulation studies are given to show how the model can be used in setting priorities on those variables that have the greatest influence on plant responses. (Auth.)
MODEL TYPE: mechanistic
COMMENT: An important model with many applications in the assessment of environmental effects on crop performance.

<166>
Shearer, G., J. Duffy, D.H. Kohl, and B. Commoner. 1974. A steady-state model of isotopic fractionation accompanying nitrogen transformations in soil. Soil Sci. Soc. Am. Proc. 38:315-322.
ABSTRACT: A steady-state mathematical model of isotopic fractionation accompanying certain nitrogen transformations in soils is developed. The model takes into account ammonification, nitrification, and immobilization; and predicts that the 15N/14N ratios of nitrate and ammonium ion depend in part upon the ratio of the rates of immobilization and ammonification. The ratio of the rates of immobilizaton to nitrification under field conditions is unlikely to be the same as under the conditions of laboratory incubation experiments. Therefore, this prediction provides a possible explanation for differences observed between the 15N/14N ratio of nitrate extracted from soil cores and that of nitrate released during laboratory incubation of the same soils. The model described is ammenable to experimental test. If verified, an expanded version of the model may be a useful aid in the study of nitrogen transformations in the field. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be adapted to evaluate pollutant effects.

<167>
Sheedy, J.D., F.L. Johnson, and P.G. Risser. 1973. Model for phosphorus and potassium flux in a tall-grass prairie. Southwest. Nat. 18(2):135-149.
ABSTRACT: A mechanistic simulation model is presented for the dynamics of phosphorus and potassium in a tall-grass prairie ecosystem in northeastern Oklahoma. Values for certain abiotic factors in 1970 were used as input to the model. Output consisted of predicted time-series of values for the amounts of phosphorus and potassium present in the different compartments of the ecosystem. Predicted values agreed quite well in some but not all cases with observed values. (Auth.)
MODEL TYPE: parametric
COMMENT: Could be adapted to evaluate impacts on grassland ecosystems.

<168>
Sinclair, T.R., and C.T. de Wit. 1976. Analysis of the carbon and nitrogen limitations to soybean yield. Agron. J. 68(2):319-324.
ABSTRACT: Soybeans are hypothesized to be "self-destructive" since they apparently need to translocate large amounts of nitrogen from vegetative tissues during seed-fill to sustain seed growth. To assess the possible limitations of this characteristic on soybean seed yield, a simple, dynamic simulation model is developed which accounts for the availability of nitrogen and photosynthate within the plant. The simulations show that the duration of seedfill and seed yield is clearly limited by the self-destructive characteristic. Increased availability of nitrogen within the plant is required for significant increases in soybean yields. Possible alterations of the model required to mimic actual soybean seed growth are presented. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model addresses a physiological question. The impact of technology on seed yield could be partially evaluated but result would not be validated.

<169>
Sinclair, T.R., and E.R. Lemon. 1974. Penetration of photosynthetically active radiation. Agron. J. 66:201-205.
ABSTRACT: The penetration and distribution of light in leaf canopies are essential data to understanding the photosynthetic productivity of a crop. Light sensors which measure photosynthetically active radiation were constructed and traversed through the leaf canopies of six types of corn (ZEA MAYS L.) to observe radiation penetration. Under clear sky conditions two major irradiance levels were observed in the corn canopies. One irradiance level was slightly less than the total radiation above the crop and represented the occurrence of sunflecks penetrating into the canopy. The second irradiance level was much less than the first and was comprised of sky radiation and radiation scattered by leaves. However, a decrease in the amount of direct solar radiation by either an overcast sky or a low sun angle resulted in a single, broad-band irradiance level. The data on sunfleck penetration also provided a basis for testing two physical models of light penetration in leaf canopies. Data from corn planted in a uniform, hexagonal pattern was in good agreement with the Poisson model which assumes a random leaf distribution. However, the Markov chain model which introduces a frequency gap parameter, lambda, to account for nonuniform leaf distribution was required to obtain good agreement with data recorded in the canopy of corn planted in rows 76 cm apart. This was especially true for the top part of the row-planted corn where small,

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short leaves resulted in large gaps for radiation penetration. The Markov model would be necessary, for instance, to determine the penetration of photosynthetically active radiation to the leaves in the middle of the canopy. Nevertheless, the Poisson model gave good agreement with the measured values for radiation intercepted by the entire canopy of the row-planted crop. (Auth.)
MODEL TYPE: parametric
COMMENT: Useful alternative representation of light dissipation in a crop to the Bouguer-Lambert law.

<170>
Spedding, C.R.W. 1971. Agricultural ecosystems. Outlook Agric. 6:242-247.
ABSTRACT: The definition of a particular agricultural ecosystem is inherently difficult, partly because of the complexity of even the simplest system and partly because of the diffuse character of its periphery. Nevertheless, the general concept of agricultural ecosystems has gained widespread acceptance in scientific circles. This is fortunate, as an understanding of the concept is indispensable in any consideration of the role of agriculture in the economy of this fragile world of ours. (Auth.)
MODEL TYPE: conceptual
COMMENT: Outlines a systems analysis viewpoint of agricultural ecosystems.

<171>
Splinter, W.E. 1974. Modelling of plant growth for yield prediction. Agric. Meteorol. 14:243-253.
ABSTRACT: A corn growth model is presented which requires three basic input parameters: average daily light intensity (ly), average daily temperature (deg. C) and soil resistance block reading (ohm). Comparison with field measurements taken during the summer of 1972 indicates reasonable fit, although the wet season did not allow a test of the soil moisture component of the model. (Auth.)
MODEL TYPE: parametric
COMMENT: Model is tuned for Nebraska conditions and could be adapted for assessment.

<172>
Stevens, T.H., and T.W. Hazelton. 1976. Sulfur dioxide pollution and crop damage in the four corners region: A simulation analysis. Agric. Exp. Sta. Bull. 647.
ABSTRACT: A simulation model was developed to forecast the impact of sulfur dioxide pollution upon crop yields in the Four Corners region. Alfalfa, which is extremely sensitive to sulfur dioxide, and winter wheat, which is less susceptible, were selected for analysis. Impacts were evaluated by simulating the relationship between the concentration of sulfur dioxide, the duration of exposure, leaf area, and yield. Three policy implications were derived from the analysis. First, a comparison of monitored sulfur dioxide concentrations with the concentrations which were calculated to produce crop damage indicates that economic losses are probably not occurring as a result of sulfur dioxide pollution in the Four Corners region. Second, it was concluded that the existing ambient air quality standards for 3 and 24 hours are sufficient to prevent damage to agricultural crops. Third, since agricultural crops can be damaged by a short-term exposure to sulfur dioxide, it is recommended that federal and state governments consider the establishment of a one-hour sulfur dioxide air quality standard of 1.18 ppm or less. Further research is recommended to evaluate the possible synergistic effect of sulfur dioxide, nitrogen oxides, and other atmospheric pollutants. (Auth.)
MODEL TYPE: parametric
COMMENT: The model is relatively simple and could be applied in other assessment situations.

<173>
Stewart, D.W., and E.R. Lemon. 1969. The energy budget at the earth's surface: A simulation of net photosynthesis of field corn. Research and Development Technical Report ECOM 2-68 1-6, U.S. Army Electronics Command, Atmospheric Sciences Lab., Fort Huachuca, AZ.
MODEL TYPE: mechanistic
COMMENT: Report provides an extensive overview of the soil-plant-atmosphere model (SPAM) that has been used extensively in agricultural modeling research. Model can be adapted for assessment of technology impacts.

<174>
Takakura, T., J. Goudriaan, and W. Louwerse. 1975. A behaviour model to simulate stomatal resistance. Agric. Meteorol. 15:393-404.
ABSTRACT: The purpose of the present study is to make a behaviour model which might have a different structure from the real system but acts in the same way as the real system does in the region considered. In the present model, the basic working hypotheses are a functional relationship between stomatal resistance and internal CO(2) concentration and an effect of leaf temperature on internal resistance. It is found that stomatal resistance in the model responds to changes in light, external CO(2) concentration and leaf temperature in a way which is experimentally confirmed. At the present stage of work on plant growth simulation, the model may be good enough to account for the rather complicated interactions that govern stomatal movement, although some clear phenomena cannot be explained. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This model can be included in more comprehensive plants models. Impacts on stomatal behaviour could be evaluated.

<175>
Takami, S., and C.H.M. van Bavel. 1975. Numerical experiments on the influence of CO(2) release at ground level on crop assimilation and water use. Agric. Meteorol. 15:193-203.
ABSTRACT: A model to simulate the effect of increased carbon dioxide levels on the gas exchange by a crop canopy was developed. The distribution of carbon dioxide in the canopy, released from a ground level area source, was calculated by a method reported elsewhere. In this submodel, the wind speed in the crop surface boundary layer, the CO(2) concentration at the upwind edge of the release area, the CO(2) release rate, and the aerodynamic canopy parameters (crop height, zero-plane displacement and roughness length) were the inputs. The radiant energy distribution inside the canopy was computed by a modified Duncan-Stewart submodel, using leaf architecture and optics as inputs. Using the outputs of the submodels and the air temperature, dewpoint and effective soil water potential as inputs, a leaf gas and energy exchange submodel calculated CO(2) and water vapor fluxes for each leaf layer, each characterized by physiological parameters that were assumed constant with height. The

APPENDIX A
Agricultural Models (continued)

<175> CONT.
gas exchange of two sorghum canopies was calculated by the proposed model for a crop growth in central Texas. The efficiency of CO(2) enrichment (the increase in the CO(2) assimilation rate divided by the CO(2) release rate) was significant only at a high irradiance level and a low wind speed. An efficiency of 13% was predicted for a sparse and rough canopy at a global irradiance of about 1,000 W/m**2 and at a wind speed of 0.5 m/sec. It was 16% for a dense and smooth canopy. The CO(2) concentration halfway into the denser canopy was 3.6 g/m**3 (1,997 ppm) higher than the ambient level, at a wind speed of 0.5 m/sec at 2 m height, for a release rate of 0.01 g/m**2/sec (360 kg/ha/h). When CO(2) was continuously released in a sparse and rough canopy during a calm (average wind speed of 1.2 m/sec) and clear day at a rate of 36 g/m**2/h, the CO(2) concentration at the crop height was maintained at around 390 ppm. Daytime CO(2) assimilation was increased from 64 g/m**2 without release to 88 g/m**2 with release. The efficiency in this case was 8%, and would have been 5% for a dense and smooth canopy. The daily water use efficiency (crop assimilation divided by the crop water use) was enhanced from 0.7% to 1.1%. The results indicate that the proposed model is useful to evaluate the possibilities of CO(2) enrichment in field crops in terms of crop CO(2) assimilation and water use under steady state conditions. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used to evaluate elevated atmospheric CO(2) levels in agricultural crops.

<176>
Taylor, H.M., and B. Klepper. 1975. Water uptake by cotton root systems: An examination of assumptions in the single root model. Soil Sci. 120:57-67.
ABSTRACT: Several mathematical models have been developed to describe water uptake by plant root systems. These models usually incorporate one or more of the assumptions that water is proportional to rooting density, to soil hydraulic conductivity, and to the water potential difference between the root surface and that in bulk soil midway between two adjacent roots. An experiment was conducted with cotton (GOSSYPIUM HIRSUTUM) at the Auburn rhizotron to test the validity of these three assumptions. Soil water potential, soil hydraulic conductivity, water uptake, and rooting density were measured or estimated as functions of soil depth and time. Average plant water potential for a water extraction period was estimated from pressure chamber and continuous stem diameter measurements. The assumption that water uptake is proportional to rooting density was valid. However, there appeared to be a large resistance in the pathway from root epidermis to root xylem. The other two assumptions must be modified to include this resistance. Therefore, water uptake was proportional to the water potential difference between root xylem and bulk soil and to the hydraulic conductivity of the combined soil-root pathway. There was no depth-of-roots effect on the validity of these relationships. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological research model and unlikely to be useful for assessment needs.

<177>
Thornley, J.H.M. 1972. A balanced quantitative model for root:shoot ratios in vegetative plants. Ann. Bot. 36:431-441.
ABSTRACT: The vegetative growth of a two-component plant consisting of root and shoot only is considered in terms of the transport and utilization of two required substrates, one providing carbon and the other providing nitrogen. The model provides a quantitative scheme for examining how root:shoot ratios depend upon the specific activities of root and shoot and hence environment. It has been shown that the total shoot activity is proportional to the total root activity in a plant undergoing steady-state growth. (Auth.)
MODEL TYPE: parametric
COMMENT: Physiological research model that could be adapted to assessment purposes.

<178>
Thornley, J.H.M. 1972. A model of a biochemical switch and its application to flower initiation. Ann. Bot. 36:861-871.
ABSTRACT: A simple biochemically based model is constructed that exhibits switching behaviour with two stable steady states. It may be used for describing systems with alternative pathways of development. Its application to vegetative and flowering growth in plants is discussed in qualitative terms. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological research model not directly suitable for assessment.

<179>
Thornley, J.H.M. 1972. A model to describe the partitioning of photosynthate during vegetative plant growth. Ann. Bot. 36:419-430.
ABSTRACT: An approach is described to the problem of modelling quantitatively the partitioning of photosynthate during vegetative plant growth. Two plant processes are important in the scheme: the first of these is the utilization of substrate for growth and how this utilization depends upon substrate concentration, the second concerns the transport of substrate between different plant parts and how this depends upon the substrate concentrations in the plant parts. In both cases simple phenomenological relations have been assumed which seem to be in reasonable accord with experimental data and with more basic theoretical considerations. The model is able to describe some of the features of steady-state vegetative plant growth in a natural manner. The limitations of the present formulation are considered, and the implications of this type of approach for whole-plant models are discussed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological research model that has been used in whole plant growth models. Model could be adapted for assessment studies.

<180>
Thornley, J.H.M. 1974. Light fluctuations and photosynthesis. Ann. Bot. 38:363-373.
ABSTRACT: The effects of fluctuating light on photosynthesis are examined. A simple model of leaf photosynthesis is used so that the analysis can be presented in explicit terms, the time-dependent problem is solved, and the response of photosynthesis to step changes in light-flux density is calculated. The presence of light fluctuations can cause a discrepancy between measurements and estimates of photosynthesis; the relevant factors are the response time of the device used for measuring light-flux density, the response time of the photosynthetic system in the leaf, and the steady-state light response curve with the degree of non-linearity and the value of the light-flux density for

APPENDIX A
Agricultural Models (continued)

<180> CONT.
maximum photosynthesis being especially important. Some general methods for estimating practically the effects of light fluctuations on photosynthesis are described. The use of the methods of time-series analysis in such problems is discussed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological research model that could be adapted for assessment applications.

<181>
Thornley, J.H.M., and R.G. Hurd. 1974. An analysis of the growth of young tomato plants in water culture at different light integrals and CO(2) concentrations. Ann. Bot. 38:389-400.
ABSTRACT: The growth analysis data of the preceding paper are examined in terms of a model. The model assumes that plant material can be divided into two categories: structure, and storage; it is further supposed that storage is the substrate for structural growth, and that the rate of structural growth depends on the amount of storage substrate present. The model has three parameters, one of which relates to the source, and the other two characterize the sink. The model gives a reasonable description of the data considered, suggesting that, in the vegetative tomato for a given temperature, the major effect of the treatments was on net assimilation rate; the changes observed in relative growth rate and leaf area ratio were then a result of the altered net assimilation rate. It also suggests that, over the range of environments considered, the relative growth rate cannot be ascribed to source or sink alone, but both are important determinants of growth. (Auth.)
MODEL TYPE: parametric
COMMENT: A growth analysis model that could be applied to greenhouse crop impacts of technology.

<182>
Thornthwaite, C.W., J.R. Mather, and J.K. Nakamura. 1960. Movement of radiostrontium in soils. Science 131:1015-1019.
MODEL TYPE: parametric
COMMENT: Could be applied to pollutant leaching assessments in agricultural soils although more mechanistic models are now available.

<183>
Tjepkema, J.D., and C.S. Yocum. 1973. Respiration and oxygen transport in soybean nodules. Planta (Berl.) 115:59-72.
ABSTRACT: The respiration rate of individual soybean (GLYCINE MAX Merr.) nodules was measured as a function of pO(2) and temperature. At 23 deg., as the pO(2) was increased from 0.1 to 0.9 atm, there was a linear increase in respiration rate. At 13 deg., similar results were obtained, except that there was an abrupt saturation of respiration at approximately 0.5 atm pO(2). When measurements were made on the same nodule, the rate of increase in respiration with pO(2) was the same at 13 deg. and 23 deg. Additional results were that 5% CO in the gas phase had no effect on respiration, except for a small decrease in the pO(2) at which respiraion became saturated. Also, nodules still attached to the soybean root displayed the same respiratory behavior as detached nodules. A model for oxygen transport in the nodule is presented which explains these results quantitatively. The essence of the model is that the respiration rate of the central tissue of the nodule is almost entirely determined by the rate of oxygen diffusion to the respiratory enzymes. Evidence is given that the nodule cortex is the site of almost all of the resistance to oxygen diffusion within the nodule. (Auth.)
MODEL TYPE: mechanistic
COMMENT: This study uses the model described by Lommen et al (1971) Planta 98:195-220. Its adaptation to oxygen transport to nodules may also be used for assessment although the model is oriented to physiological research.

<184>
Torssell, B.W.R., and A.O. Nicholls. 1976. A comparison between two models for plant competition. Aust. J. Ecol. 1:29-35.
ABSTRACT: The differential equation of de Wit (1970) which predicts the growth of plant species in mixtures from their yield-density response in monocultures is compared with a simpler equation. This model is also based on the yield-density response of species grown in monocultures, but is static and predicts only the net result of plant competition during discrete time periods. Data from successive harvests in yield-density experiments in monocultures of one grass and two legume species were fitted to both models and the relative reproductive rate and the relative replacement rate were calculated from model predictions. Predictions from our model agreed more closely with observations than predictions from the de Wit model. It is concluded that our model deserves further attention in the studies of population dynamics in mixtures when the final outcome of competition is the main interest. (Auth.)
MODEL TYPE: parametric
COMMENT: Model could be adapted to evaluate technology impacts on plant competition.

<185>
Travis, J.R. 1974. A model for predicting the redistribution of particulate contaminants from soil surfaces. In: Engelmann, R.J.; Schmel, G.A. (eds.), Atmosphere-surface exchange of particulate and gaseous pollutants, pp. 906-944. ERDA Symp. series 38. Technical Information Center, DOE, Washington, DC.
ABSTRACT: A computerized model was developed to describe the redistribution of wind-eroding soil-contaminant mixtures. Potentially mobile particulate contaminants can, in the first approximation, be assumed to be indistinguishable from the wind-eroding soil in which they are distributed. A grid network characterizes important soil and surface conditions, and mass conserving control volumes are constructed on each cell. Material is transported through the vertical and to surfaces of a control volume by a modified Bagnold-Chepil horizontal flux formulation and modified Gillette vertical flux formulation, respectively. The vertical emissions, considered as puffs from area sources, create at regular time intervals a contaminant cloud proportional to the suspendable ground concentration. These puffs diffuse downwind under time-dependent wind velocity and atmospheric stability conditions, maintaining during the interval a three-dimensional Gaussian distribution of concentrations with cloud volume. Material from each puff is deposited in downwind cells, leading to the possibility of many different flights from these new sources. The usefulness of this predictive tool is demonstrated by calculations involving mixtures of particulate 238PuO(2) in highly erodible soils under dust storm conditions. Time-dependent surface concentration and breathing zone exposure isopleths, evolving from a small contaminated area, show the

APPENDIX A
Agricultural Models (continued)

<185> CONT.
potential hazard from wind-eroding toxic materials. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model could be applied to evaluate material transport to and within agricultural fields from technology sources.

<186>
Truesdell, A.H., and B.F. Jones. 1974. WATEQ, a computer program for calculating chemical equilibria of natural waters. J. Res. U.S. Geol. Survey 2:233-248.
ABSTRACT: The computer program, WATEQ, calculated the equilibrium distribution of inorganic aqueous species of major and important minor elements in natural waters using the chemical analysis and in situ measurements of temperature, pH, and redox potential. From this model, the states of reaction of the water with solid and gaseous phases are calculated. Thermodynamic stabilities of aqueous species, minerals, and gases have been selected from a careful consideration of all available experimental data. The program is written in PL-1 for IBM 360 computers. (Auth.)
MODEL TYPE: mechanistic
COMMENT: A detailed model that could evaluate impacts of temperature, pH and redox potential changes on chemical equilibria of well water and streams.

<187>
van Bavel, C.H.M. 1975. A behavioral equation for leaf carbon dioxide assimilation and a test of its validity. Photosynthetica 9(2):165-176.
ABSTRACT: A set of two simple equations describes the joint effect of irradiance, ambient CO(2) level, and leaf diffusion resistance upon the CO(2) flux density of a leaf. The principal leaf parameters are the maximum assimilatory capacity, the efficiency of radiant energy utilization or maximum photon yield, and the CO(2) utilization efficiency. The proposed model shows the "double saturation" effect of irradiance and CO(2) level, the CO(2) efflux in the dark, and the significance of the CO(2) compensation point for the efficiency of conversion of radiant energy. It also demonstrates that the leaf diffusion resistance is critical for the shape of irradiance response curves. All leaf parameters can be obtained from common laboratory experiments. A test of the model with a sunflower leaf gave satisfactory agreement between experiment and theory. The sunflower leaf parameters were calculated for a leaf temperature of 25 deg. C. The maximum assimilatory capacity was 0.008 g/m**2/s, the CO(2) utilization efficienty 2.7 m**3/g, and the efficiency of radiant energy utilization 4.9 g/einstein, or a photon requirement of 9 einstein/mol. The proposed equations are primarily intended for use in comprehensive models of plant and canopy behavior, and of productivity and water use of plant communities. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be adapted for assessment purposes by inclusion in more comprehensive plant models.

<188>
van Bavel, C.H.M., and J. Ahmed. 1976. Dynamic simulation of water depletion in the root zone. Ecol. Model. 2:189-212.
ABSTRACT: The joint effect of the distribution of the soil water potential and of the root mass in the crop root zone upon the water uptake by the crop is represented by a simple equation. This expression is used to join a layered crop canopy model for finding the evapotranspiration, as controlled by stomatal action and the weather, with a hydraulic flow model for the root zone and the underlying soil. The complete model is used for the calculation of the water extraction pattern and the changes, with time, of other plant and soil processes. A simulation of a 20-day drying period is performed, using S/360 CSMP, for a constant diurnal weather pattern, and for a fully developed sorghum crop. The results show that, after a few days of essentially constant water use by the crop, a monotonic decline sets in that is principally attributable to the decrease in transpiration. For the entire drying period a substantial amount of water - about 30% of the total used - is contributed by upward flow into the root zone from the soil below. The results demonstrate the difficulty of quantitative definition of concepts such as "field capacity", "wilting percentage", and "available" or "extractable" water. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used for assessment in combination with a crop evapotranspiration model.

<189>
van Bavel, C.H.M., and D.I. Hillel. 1976. Calculating potential and actual evaporation from a bare soil surface by simulation of concurrent flow of water and heat. Agric. Meteorol. 17:453-476.
ABSTRACT: A numerical method is described by which the instantaneous evaporation rate from bare soil, regardless of its wetness, can be estimated from standard weather data and the physical characteristics of the soil profile. It is used to calculate potential evaporation from a surface energy balance without the commonly used approximations. The results show that the soil heat flux and the soil surface emittance may vary enough with soil water content so as to make the concept of potential evaporation ambiguous. From a practical viewpoint, however, these differences in the evaporation rate from a wet surface are not large enough to invalidate the simpler combination or energy balance formulas, in which the surface albedo and roughness are the only non-climatic parameters. The method is particularly useful in simulating the evaporation process from drying surfaces. The results support the existence of separate potential and falling rate stages of evaporation, but not that of a third, constant rate stage. A rapid increase of the diurnal amplitude of the surface temperature is the clearest indicator of the transition between the two stages. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used for assessment of impacts on soil evaporation.

<190>
van Keulen, H., and C.G.E.M. van Beek. 1971. Water movement in layered soils - A simulation model. Neth. J. Agric. Sci. 19:138-153.
ABSTRACT: A simulation model for infiltration of water in layered soils, written in CSMP (Continuous System Modeling Program), is described. The influence of the occurrence of a compacted layer or a loosened topsoil on the infiltration behavior is checked. It is concluded that this behavior can be predicted if soil parameters are available. In an appendix special attention is paid to the problem of choosing the proper size of the compartments in which the soil is divided and the necessary averaging procedure. At last

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Agricultural Models (continued)

<190> CONT.
the magnitude of the time steps is discussed. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used to evaluate infiltration and soil surface effects on water flow.

<191>
Verhagen, A.M.W., J.H. Wilson, and E.J. Britten. 1963. Plant production in relation to foliage illumination. Ann. Bot., N.S. 27:627-640.
ABSTRACT: The intensity of light received by plants can be specified in terms of its extinction with depth in the foliage. Various light-extinction functions are introduced to specify the light received by plants with different patterns of foliage development (viz. standard exponential, best exponential, and ideal). The implications of these extinction functions are discussed and the production associated with each foliage type is studied as a function of leaf area index, LAI (the ratio of leaf area to ground area). The concepts of optimum LAI and ceiling LAI are considered in relation to these foliages. It is shown that, contrary to what has previously been thought, a foliage in which the bottom leaves are at compensation point is not necessarily at optimum LAI. It also becomes possible to reconcile conflicting views on the relationship between optimum LAI and ceiling LAI. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Has limited use in assessment since other plant models are available with more comprehensive algorithms.

<192>
Waggoner, P.E. 1969. Environmental manipulation for higher yields. In: R.C. Dinauer (ed.), Physiological Aspects of Crop Yield, pp. 343-373. Am. Soc. Agron., Madison, WI.
ABSTRACT: The effect of environmental manipulation upon the photosynthesis and the yield of a crop canopy is explored by the use of mathematical models. These models or crop simulators use logical rules for calculation that not only estimate the amount of photosynthesis but also work in many ways like an actual crop. The first or microclimate simulator accepts news of the weather above, the temperature and humidity of the air beneath the canopy, as well as the canopy architecture, stomatal resistance, absorption of radiation, and ventilation. From these factors the simulator calculates evaporation and the temperature of the air and the leaves within the canopy. The second or photosynthesis simulator accepts the output of the first plus the following characteristics of the individual leaves: (1) Photochemical facility and how it varies with temperature, light and CO(2) concentration, (2) Dark respiration and how it varies with temperature, (3) Light respiration and how it varies with temperature and light and (4) The physical resistances to the current of CO(2). The second simulator also accepts the CO(2) concentration above and below the canopy and currents of that gas that are injected or advected into the canopy at different levels. From this information, the simulator calculates the CO(2) concentrations in the air and the photosynthesis in the leaves of the canopy. Manipulating the leaf pores or stomata can decrease evaporation, and the simulators indicate that photosynthesis will be decreased relatively less. This is a different outcome than from a decrease in photochemical facility, which would decrease photosynthesis relatively more than evaporation. Increasing the light either from above or below the canopy would increase assimilation nearly proportionally. Since great differences in ventilation have little effect upon assimilation, the conservation of water by shelter extracts no hidden tax of decreased delivery of CO(2) for photosynthesis. Naturally ventilated canopies are very porous. Hence, the recovery by photosynthesis of CO(2) released from dry ice or decay below or within the canopy is inefficient. On the other hand, the general increase of 0.72 ppm CO(2) per year in the earth's atmosphere will increase photosynthesis in efficient species and full sunlight by 7% between now and the end of the century. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Physiological research model with flexibility to evaluate microclimate effects on plant growth. Could be adapted to evaluate aspects of technology impacts on crop growth.

<193>
Waggoner, P.E., G.M. Furnival, and W.E. Reifsnyder. 1969. Simulation of the microclimate in a forest. Forest Sci. 15:37-45.
ABSTRACT: A model of the energy exchange within a canopy of leaves is presented in terms of three sets of equations. The sums of radiant, sensible, and latent heat exchange in several strata of the canopy are set equal to zero. Next, the potentials for the exchange of latent and sensible heat are related to the warming of the leaves. Finally, the difference in potential between adjacent strata are related to the diffusive resistances of the air within the canopy, the boundary layer, and the stomata, and to the fluxes of latent and sensible heat. This system of simultaneous linear equations is solved algebraically for the exchange of latent and sensible heat by each stratum of the canopy, for the leaf temperature of these strata, for the exchange of latent and sensible heat by the soil, and for the storage of heat within the soil. The temperature and humidity above and below the canopy, the absorption of radiation within the canopy, and the several diffusive resistances must be specified. Observations of the exchange of energy and the microclimate within a pine canopy are mimicked by the model. Nine strata are demonstrated to be an adequate number. Calculations with the model explain the effect of stomatal changes upon the evaporation from a forest. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used to evaluate effects of microclimate changes on crop evaporation in the vicinity of industrial plants.

<194>
Waggoner, P.E., and W.E. Reifsnyder. 1968. Simulation of the temperature, humidity and evaporation profiles in a leaf canopy. J. Appl. Meteorol. 7:400-409.
ABSTRACT: The proposed model synthesizes profiles of temperature, humidity and evaporation in a canopy of leaves from meteorological conditions at canopy top, from the temperature and humidity at the soil surface, from a leaf dimension, from the vertical distribution of leaf area and stomatal resistance, and from observations or extinction coefficients for ventilation and radiation within the canopy under steady-state conditions. The exchange of sensible and latent heat in a canopy stratum is required to be equal to the absorption of radiation by the leaves in that stratum.

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Agricultural Models (continued)

<194> CONT.
Further, the difference between strata in their potential for sensible and latent heat exchange is related both to leaf temperature and to the fluxes and diffusive resistances between the leaves. Leaf temperatures, evaporation and sensible heat exchange, and air temperatures within the canopy that meet these requirements were calculated by successive approximation. The microclimate and evaporation of a red clover and of a barley canopy were simulated, and changes in evaporation from a canopy following moderate changes in stomatal resistance were explained by the model. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used in assessment of technology effects on canopy microclimate.

<195>
Walker, W.M., T.R. Peck, and S.G. Carmer. 1969. Relationship between soybean yields and leaf levels of 10 elements determined with different regression models. Agron. J. 61:413-416.
ABSTRACT: Soybean leaf samples and yields were obtained from experimental plots receiving varying levels of P and K. Yields were regressed on a quadratic polynomial with leaf levels of P and K as variables. This regression had an R**2 of 0.495. Yields were regressed on a second quadratic polynomial with leaf levels of N, P, K, Ca, Mg, B, Cu, Fe, Mn, and Zn as variables. With the stepwise regression procedure used for fitting the model, 22 linear and second order terms were fitted to the data. This regression had an R**2 of 0.813. The additional variation accounted for by the second regression was statistically significant. Other polynomial regressions were fitted to the data using ratios of elements as independent variables, but none were superior to the quadratic polynomial in terms of R**2 values. (Auth.)
MODEL TYPE: statistical
COMMENT: Not readily adapted to assessment of tehcnology impacts.

<196>
Warrick, A.W. 1970. A mathematical solution to a hillside seepage problem. Soil Sci. Soc. Am. Proc. 34:849-853.
ABSTRACT: A solution is presented for a two-dimensional hillside seepage problem. The soil is assumed to be water-saturated to the soil surface where the soil water is at atmospheric pressure. Seepage occurs into the flow medium along the upper part and out along the lower part of the sloping soil surface. The flow medium is infinitely deep and bounded laterally by vertical streamlines. Conformal transformations are used to find the hydraulic head and stream functions. Although the solution is analytic, a complex integral must be evaluated numerically for application. Numerical data presented includes flownets, seepage velocities, infiltration angles, and volume of flow as a function of slope. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Potentially useful in assessment applications involving soil water drainage.

<197>
Wierenga, P.J., and C.T. de Wit. 1970. Simulation of heat transfer in soils. Soil Sci. Soc. Am. Proc. 34:845-848.
ABSTRACT: A computer model was developed to predict the temperature fluctuation in subsoil from the temperature variation at the soil surface, taking into account changes in the apparent thermal conductivity with depth below soil surface and soil temperature. The model makes use of S/360 CSMP, a recently developed simulation language for digital computers. Predicted soil temperatures were compared with soil temperatures observed at 2, 10, 15, 25, 30, and 75 cm below the surface of bare field profiles, before and after irrigation with 13.4 cm water. In wet soil observed and predicted temperatures were in close agreement. In dry soil significant differences were observed between measured and predicted soil temperatures during part of the day. The increase in apparent thermal conductivity with soil temperature had a negative effect on the magnitude of the difference between observed and predicted values in the dry soil. Agreement was found between soil heat flux density values predicted from the model and calculated with the temperature integral method. Use of a digital simulation language can save considerable programming time, and can be applied to movement of water and gases in soil profiles. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used in waste heat impact assessment.

<198>
Woo, K.B., L. Boersma, and L.N. Stone. 1966. Dynamic simulation model of the transpiration process. Water Resour. Res. 2(1):85-97.
ABSTRACT: Plant life processes are related in a complex way to the balance between the water demand of the atmosphere and the availability of water to the plant root. An exploration of the dynamic status of water in the plant is very important. As an approach to an integrated analysis of the dynamic system of water movement through the soil-plant-atmosphere continuum, a simulation model of the transpiration process is presented. Van den Honert suggested the use of Ohm's law describing water flow into, through, and out of plants. In the present study, this hypothesis has been expanded to include an analogous storage factor to deal with the dynamic flow of water in the plant. A set of differential equations and transfer functions is expressed in terms of water suction variables. The dynamic description of the water status in the plant is completed by introducing the system gain, which is a function of both the transpiration rate and the soil-water condition. The dynamic system gain is realized by a method similar to Corbin's method of a computer-controlled adaptive control system. The entire system is then simulated on an analog computer; its dynamic characteristics are investigated with consideration of various environmental effects. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Could be used in assessment. However, equivalent digital models are available.

<199>
Woo, K.B., L.N. Stone, and L. Boersma. 1966. A conceptual model of stomatal control mechanisms. Water Resour. Res. 2:71-84.
ABSTRACT: The stomata of plant leaves constitute a main regulating system of the transpiration process. Biologists have suggested a turgor mechanism to explain stomatal movement. The functions of the mechanism are quantitatively described by an osmotic water transfer theory and/or the active water transfer theory in the guard cells. Based on the active water transfer theory and the observations of stomatal movement under various conditions of H(2)O, CO(2), and light, a conceptual model of the stomatal control mechanism is proposed. Transfer functions of the

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mechanisms characterizing the changes in turgor pressure have been derived. The entire system has been organized by the application of adaptive control system theory and has been simulated on an analog computer. The dynamic characteristics have been investigated with consideration of various environmental conditions. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Research model with too much detail for assessment purposes.

<200>
Yang, S.J., and E. de Jong. 1971. Effect of soil water potential and bulk density on water uptake patterns and resistance to flow of water in wheat plants. Can. J. Soil Sci. 51:211-220.
ABSTRACT: Water uptake patterns of wheat plants were studied in a growth chamber by using two soils packed to three different bulk densities. The resistances to water movement in the soil and in the plant were calculated from the mathematical model for water uptake published in the literature. When the capillary potential of the soils was near -1/3 bar, withdrawal of water by plants was relatively small and most of the water was taken from the top 25 cm of the soil column. As soil water potential decreased, water uptake increased progressively toward the lower part of the soil column. The resistance to water movement in the plant increased from the top to the bottom of the root system and increased with increasing bulk density of the soils. For wet soils, unrealistic values were obtained which could be due to the fact that the interaction between aeration and moisture uptake is not taken into account in the theoretical equations for moisture uptake. (Auth.)
MODEL TYPE: mechanistic
COMMENT: Model evaluates a specific root characteristic and is not suitable for assessment.

APPENDIX B

AUTHOR INDEX

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