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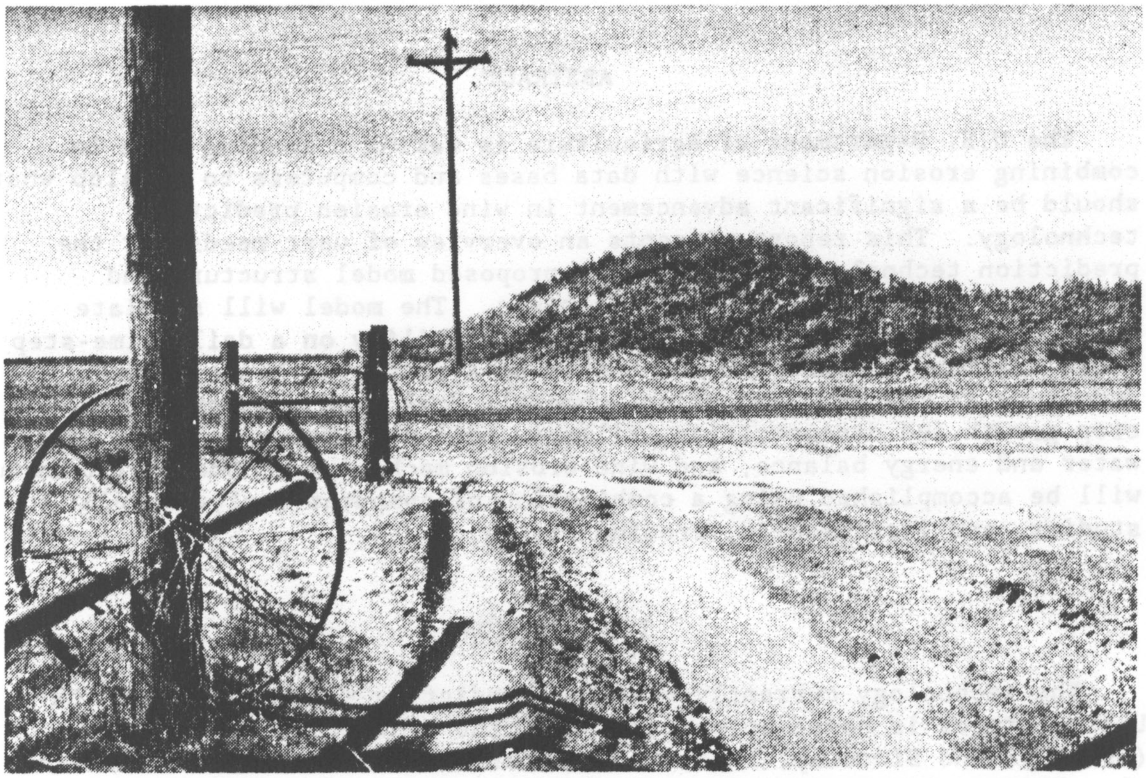
1988 WIND EROSION CONFERENCE



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NEW WIND EROSION MODEL DEVELOPMENTS IN THE USDA

by

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ABSTRACT

The U.S. Department of Agriculture is taking a leading role in combining erosion science with data bases and computers to develop what should be a significant advancement in wind erosion prediction technology. This report presents an overview of user needs for the prediction technology, along with a proposed model structure and validation procedure to meet those needs. The model will simulate those factors that control field wind erodibility on a daily time-step basis and then compute erosion events on a subhourly basis. The structure is modular, and major submodels deal with weather generation, crop growth and decomposition, tillage, soil temporal properties, soil water and energy balance, and wind erosion mechanics. Model validation will be accomplished using a combination of computer analyses, plot studies, and instrumented, eroding fields.

INTRODUCTION

The technology currently used for predicting wind erosion in the United States is based on variations of the Wind Erosion Equation (Woodruff and Siddoway, 1965; Skidmore and Woodruff, 1968; and Cole et al., 1983). This prediction system uses erosion loss estimates that are integrated over large fields and long time scales to produce average annual values. Because of the time and space scales involved, the current technology is a mature one, which is not easily adapted to new or untested conditions. However, the widespread availability of personal computers would allow most users of erosion prediction systems to adopt a flexible, process-based technology.

Currently, the U. S. Department of Agriculture is taking a leading role in combining erosion science with data bases and computers to develop what should be a significant advancement in wind erosion prediction technology. In 1986, an initial group composed of Agricultural Research Service (ARS) and Soil Conservation Service (SCS) scientists was formed to begin development of a new Wind Erosion Prediction System (WEPS). Additional scientists are now being added to the group to strengthen specific research and technology development areas. The objective of the project is to develop replacement technology for the Wind Erosion Equation. In this report, an overview of user needs for wind erosion prediction technology is presented, along with a model structure and validation procedure to meet those needs.

USER NEEDS

The primary user of wind erosion prediction technology is the USDA Soil Conservation Service, which has several major applications. First, as a part of the periodic National Resource Inventory, it collects data at 300,000 primary sampling points and, at central locations, calculates the erosion losses occurring under current land use practices. The analyzed results are used to aid in developing regional and national policy.

Second, SCS does conservation planning of wind erosion control practices to assist farmers and ranchers in meeting erosion tolerances. Implementation of adequate conservation plans preserves land productivity and reduces both on-site and off-site damages. Conservation planning requires a prediction system that will operate on a personal computer and produce answers in a relatively short time. In addition, WEPS must serve as a communication tool between conservation planners and those who implement the plans.

Various users also undertake project planning in which erosion prediction is used to evaluate erosion and deposition in areas impacted by the project. In this application, more time and resources may be expended than in conservation planning to collect input data and make analyses. Project planning is typically carried out by multidisciplinary teams including field personnel who collect needed input data.

Other users of wind erosion prediction technology represent a wide range of problem areas. Often their problems will require development of additional models to supplement WEPS in order to obtain answers of interest. Some of these diverse problem areas include evaluating new erosion control techniques, estimating long-term soil productivity changes, calculating on-site and off-site economic costs of erosion, finding deposition loading of lakes and streams, computing the effects of dust on acid rain processes, determining impact of management strategies on public lands, and estimating visibility reductions near airports and highways.

From the preceding survey of user needs, it is apparent that the prediction technology must deal with a wide range of soil types and management factors. Wind erosion prediction technology also must cover a broad range of climatic and geographic regions in the U. S. The major impact of wind erosion is in the Great Plains; but erodible areas in the Great Lakes region, the semi-arid western U. S., and windy coastal regions are all affected (Fig. 1).

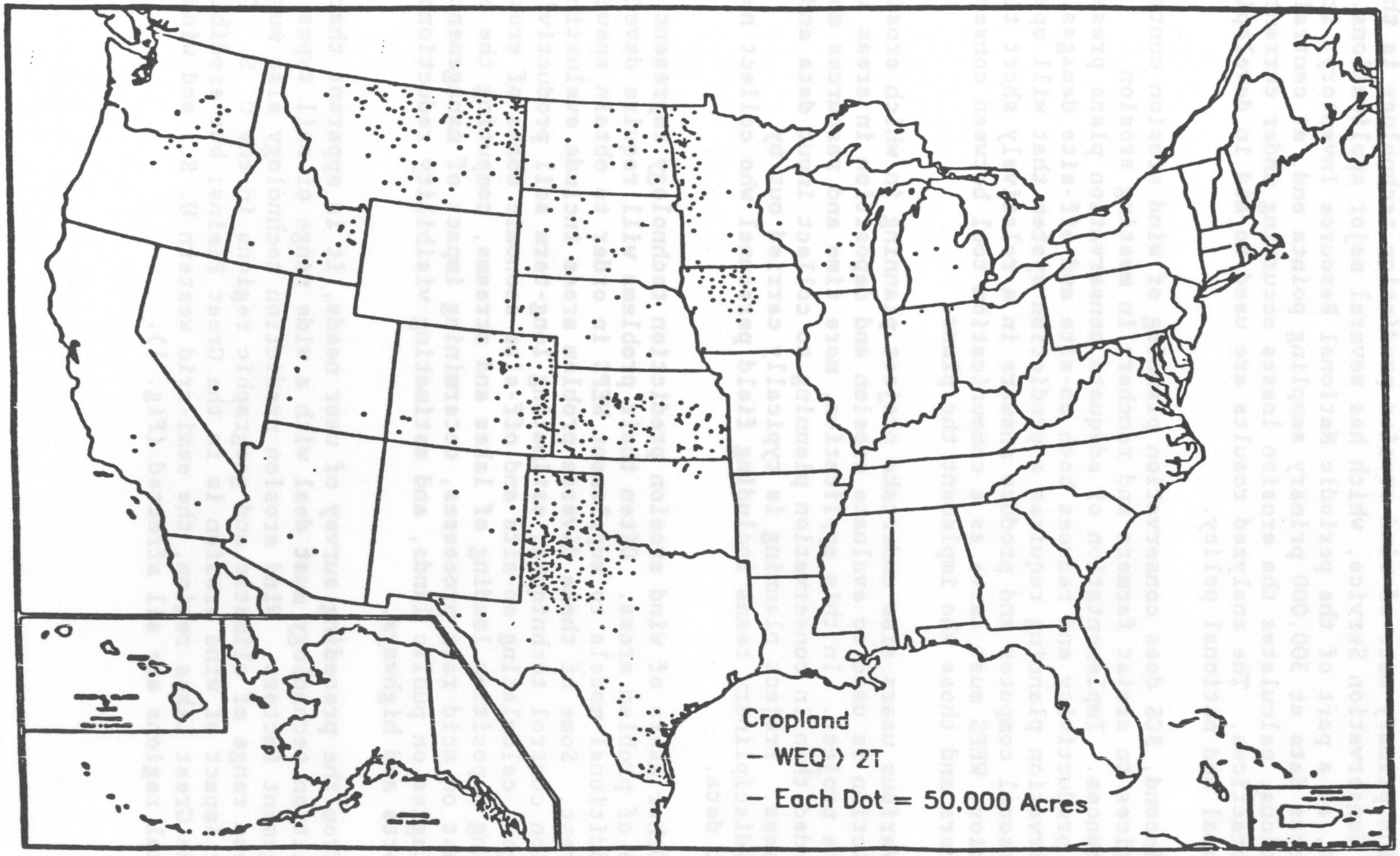

Fig. 1. Cropland areas in the United States where the Wind Erosion Equation (WEQ) predicts annual soil losses average more than twice the erosion tolerance level (T).

OVERVIEW OF MODEL

The model development process has two major stages. The objective of the first stage is to develop a wind erosion research model (WERM). This will be a daily simulation model written in FORTRAN 77, which can be validated and used as a reference standard for wind erosion predictions. In the second stage of development, the submodels in WERM will be reorganized to increase computation speed, the data bases will be expanded in size, and a user-friendly input/output section will be added to produce the final WEPS. In addition, a different computer language may be selected for WEPS to enhance program graphics, speed, and portability.

In the model, the simulation region will be one field or, at most, a few adjacent fields (Fig. 2). In most cases, the user will locate the boundaries of the simulation region along borders that are not crossed by saltating particles, to simplify specification of boundary conditions. When computing soil loss, grid points will overlay the computation region, and the user may select any subset of the grid points as a soil loss accounting region from which to get model output. Grid points on the field will likely be spaced only a few meters apart. However, their spacing will ultimately depend on gradients of field surface variables and the desired computational accuracy. Model output will be the average soil loss/deposition over the accounting region for a user-selected time interval. The model also will have an option to provide users with individual loss components for the creep, saltation, and suspension fractions, as well as individual accounting for deposition of creep and saltation fractions.

The structure of WERM is modular and consists of a MAIN (supervisory) program and five submodels along with their associated data bases (Fig. 3). An important function of the MAIN program is to query users for the needed user-inputs and permit selection of output options. The modular structure permits members of the modeling team to easily test and update specific sections of the model during development. It will also facilitate model maintenance as new technology is developed. In general, the submodels are based on fundamental processes occurring in the field. Extensive experimental work is being carried out simultaneously with model development and is mainly devoted to delineating parameter values that describe the processes.

SUBMODEL CONCEPTS

Because the model deals with prediction of future events, the objectives of the CROP, TILLAGE, and SOIL submodels are to predict the temporal soil and vegetative cover variables, which control soil erodibility in response to inputs generated by the WEATHER submodel. Finally, if wind speeds are above the erosion threshold, the EROSION submodel computes soil loss or deposition over the simulation region. The function of each submodel and its data base will now be outlined in more detail.

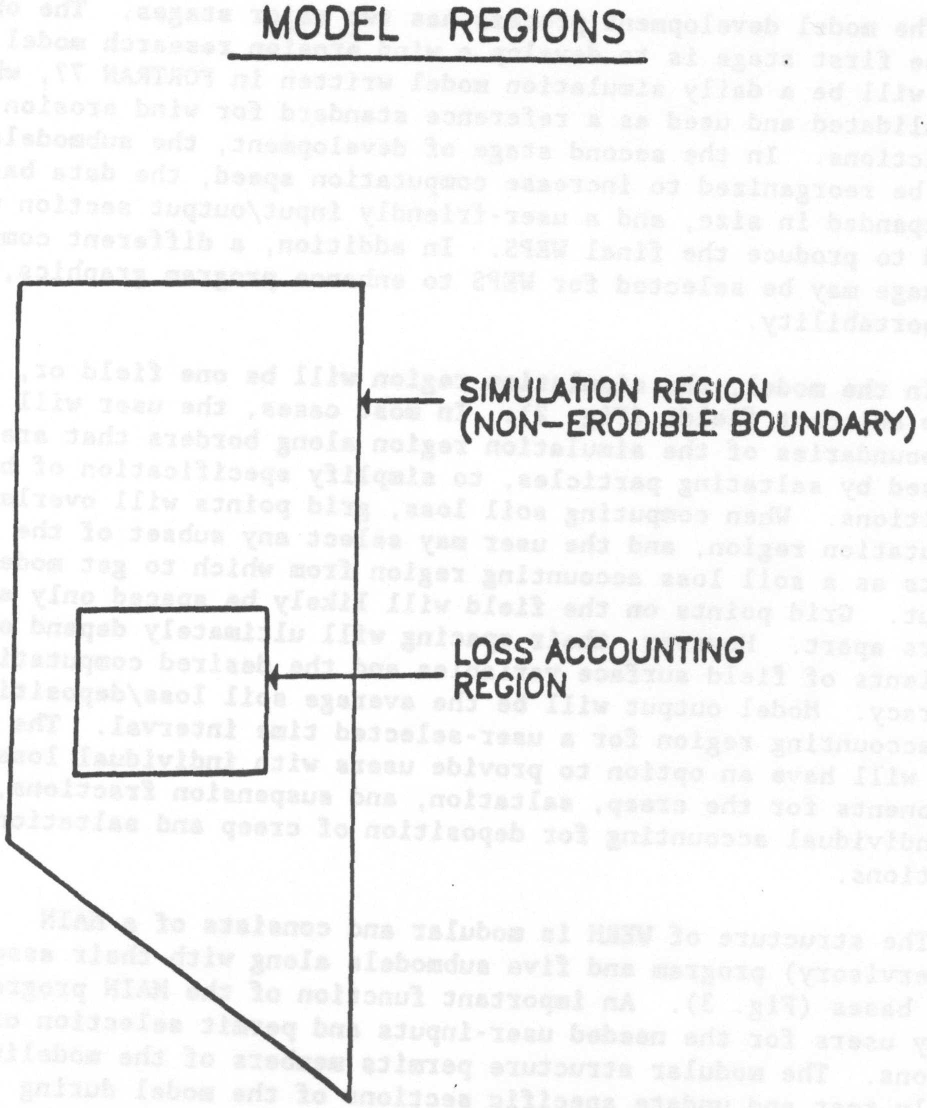

Fig. 2. Schematic of the simulation region where soil loss or deposition is computed on a grid overlaying the field-scale simulation region, and users can select any subset of the grid points as the loss or deposition accounting region.

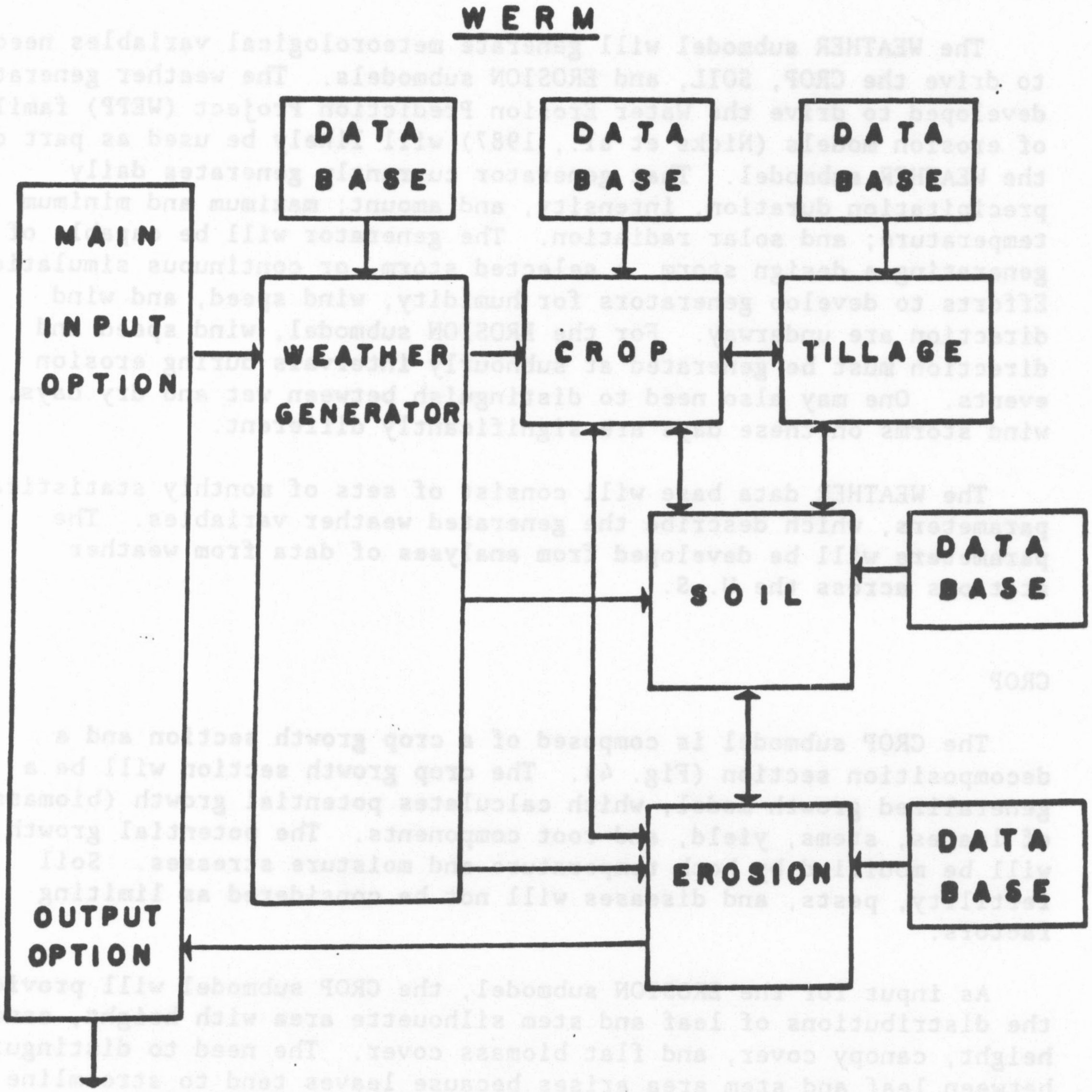

Fig. 3. Schematic of Wind Erosion Research Model (WERM) and associated data bases.

WEATHER

The WEATHER submodel will generate meteorological variables needed to drive the CROP, SOIL, and EROSION submodels. The weather generator developed to drive the Water Erosion Prediction Project (WEPP) family of erosion models (Nicks et al., 1987) will likely be used as part of the WEATHER submodel. That generator currently generates daily precipitation duration, intensity, and amount; maximum and minimum temperature; and solar radiation. The generator will be capable of generating a design storm, a selected storm, or continuous simulation. Efforts to develop generators for humidity, wind speed, and wind direction are underway. For the EROSION submodel, wind speed and direction must be generated at subhourly intervals during erosion events. One may also need to distinguish between wet and dry days, if wind storms on these days are significantly different.

The WEATHER data base will consist of sets of monthly statistical parameters, which describe the generated weather variables. The parameters will be developed from analyses of data from weather stations across the U. S.

CROP

The CROP submodel is composed of a crop growth section and a decomposition section (Fig. 4). The crop growth section will be a generalized growth model, which calculates potential growth (biomass) of leaves, stems, yield, and root components. The potential growth will be modified by both temperature and moisture stresses. Soil fertility, pests, and diseases will not be considered as limiting factors.

As input for the EROSION submodel, the CROP submodel will provide the distributions of leaf and stem silhouette area with height, canopy height, canopy cover, and flat biomass cover. The need to distinguish between leaf and stem area arises because leaves tend to streamline with the flow and have a drag coefficient (C_d) of about 0.1, whereas stems tend to remain rigid and have a C_d of about 1.0. Thus, on a unit area basis, stems are about 10 times more effective than leaves in depleting the shearing stress transmitted to the canopy.

The decomposition section will keep account of the biomass residues in standing, flat, and buried categories. Such factors as crop carbon-nitrogen ratios, temperature, and moisture will be used to drive the rates of decomposition. In addition to the biomass flow paths depicted in Fig. 4, there will be a biomass sink called harvest, initiated by the TILLAGE submodel, which will remove biomass from some of the categories.

The CROP data base will contain information on specific crops and include parameters on growth, leaf-stem relationships, decomposition, and harvest.

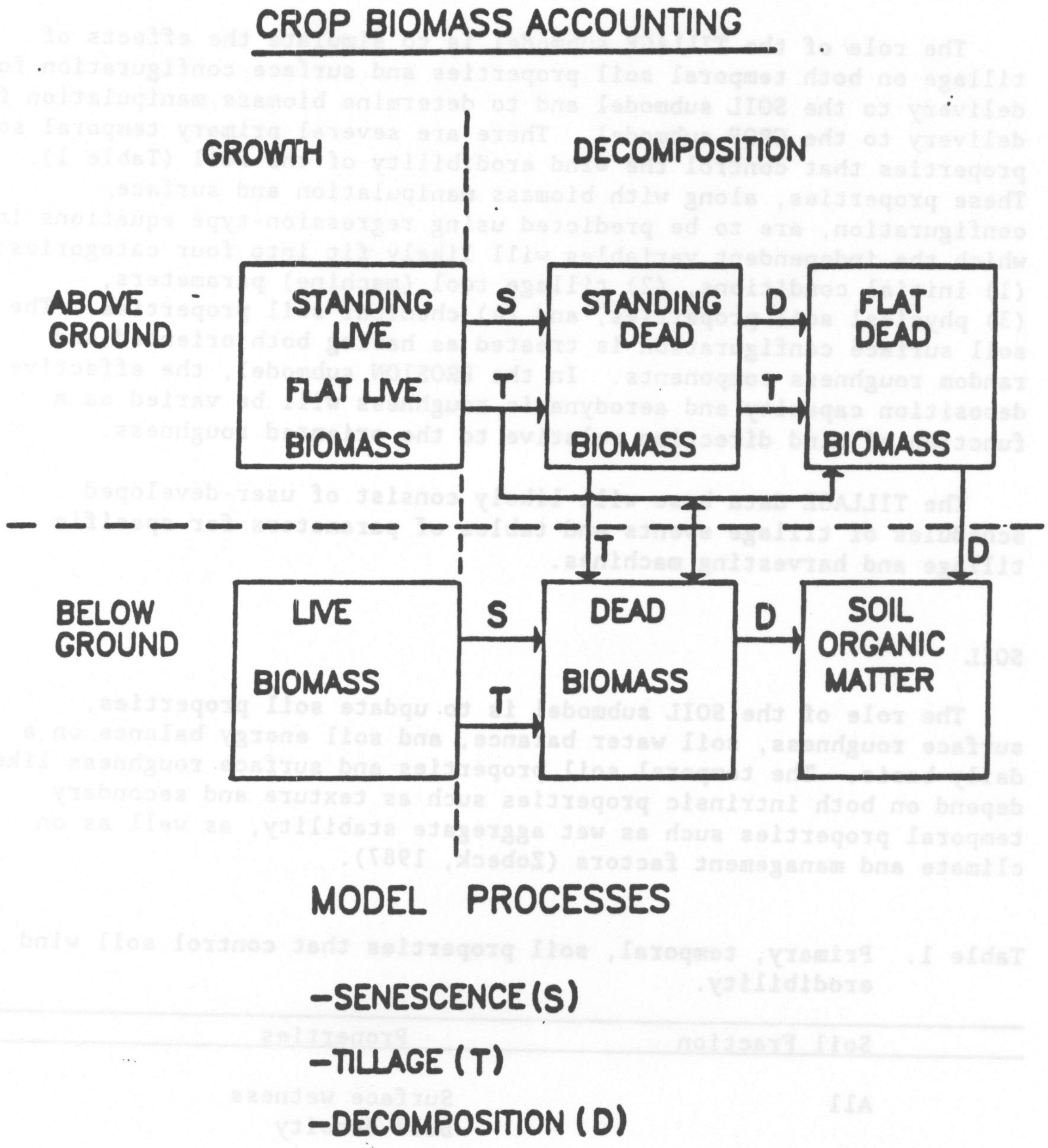

Fig. 4. Schematic of biomass accounting in the CROP submodel.

TILLAGE

The role of the TILLAGE submodel is to simulate the effects of tillage on both temporal soil properties and surface configuration for delivery to the SOIL submodel and to determine biomass manipulation for delivery to the CROP submodel. There are several primary temporal soil properties that control the wind erodibility of the soil (Table 1). These properties, along with biomass manipulation and surface configuration, are to be predicted using regression-type equations in which the independent variables will likely fit into four categories: (1) initial conditions, (2) tillage tool (machine) parameters, (3) physical soil properties, and (4) chemical soil properties. The soil surface configuration is treated as having both oriented and random roughness components. In the EROSION submodel, the effective deposition capacity and aerodynamic roughness will be varied as a function of wind direction relative to the oriented roughness.

The TILLAGE data base will likely consist of user-developed schedules of tillage events and tables of parameters for specific tillage and harvesting machines.

SOIL

The role of the SOIL submodel is to update soil properties, surface roughness, soil water balance, and soil energy balance on a daily basis. The temporal soil properties and surface roughness likely depend on both intrinsic properties such as texture and secondary temporal properties such as wet aggregate stability, as well as on climate and management factors (Zobeck, 1987).

Table 1. Primary, temporal, soil properties that control soil wind erodibility.

Soil Fraction	Properties
All	Surface wetness Bulk density
Aggregates	Size distribution Dry stability Density
Crust	Depth Dry stability Loose soil above Cover fraction Density

In order to assess the water balance, the SOIL submodel will account for infiltration, snowmelt, runoff, deep percolation, evaporation, and plant water use. Wind redistribution of snow will also be accounted for in this submodel. The soil energy balance will be calculated and the soil temperature profile computed. Soil freeze/thaw cycles and frost depth will also be modeled.

The SOIL data base will consist of the intrinsic soil properties that are shown to be useful in predicting the temporal soil properties.

EROSION

The EROSION submodel will perform several major tasks. The first task is to compute the surface threshold friction velocities over the simulation region, considering the effects of flat cover, surface roughness, and primary temporal soil properties. The second task is to compute field surface friction velocities based on the wind speed and direction supplied by the WEATHER submodel, considering the effects of hills, barriers, standing canopies, and surface roughness.

During periods when friction velocity exceeds the threshold friction velocity, soil loss and deposition will be computed over the simulation region at subhourly intervals. A computational control volume for bare soil is illustrated in Fig. 5. The erosion process is modeled as the time-dependent conservation of mass of two species (saltation and creep size aggregates) with two sources of erodible material (emission and abrasion) and two sinks (surface trapping and suspension). At each time step, the lower surface boundary conditions are updated in response to the loss or deposition that has occurred.

The source and sink terms represent distinct physical subprocesses that can occur during wind erosion. Emission occurs when there is a net loss of loose saltation/creep-size aggregates caused by a combination of wind shear and saltation impact forces. This loss is typical of the data obtained in wind tunnel tests on soil aggregates (Chepil, 1950; Fryrear, 1984). Trapping occurs when there is net deposition of saltation/creep-size material over a portion of the control volume surface such as between ridges or random roughness projections (Hagen and Armbrust, 1985). Abrasion is used here to mean the breakdown of nonerodible size clods and crust to wind-erodible sizes. This subprocess depends on the rate of impaction of saltating aggregates and the stability of the target, as well as on other factors (Hagen, 1984).

Sources of the suspension-size material include direct emission from among the soil aggregates, as well as creation of additional material abraded from the clods, crusts, and impacting aggregates during erosion (Hagen and Lyles, 1985). The magnitude of the suspension component varies widely among fields (Gillette, 1977). In the model, the suspended material is regarded as lost through the top of the control volume, so its deposition is not considered, because it generally occurs over a much larger area than that encompassed by the simulation region.

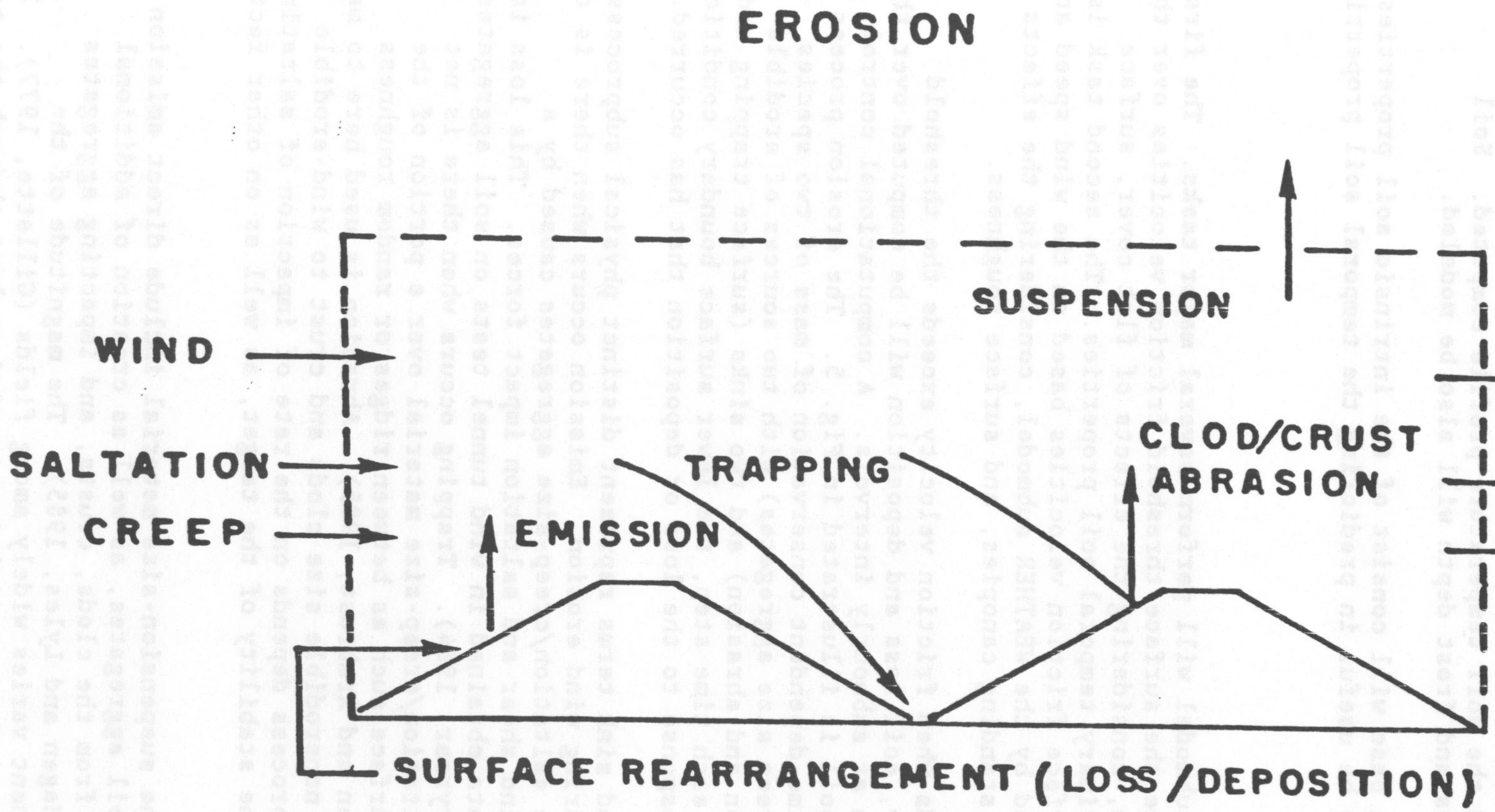

Fig. 5. Schematic of a control volume for the EROSION submodel with bare soil.

In the EROSION submodel, standing vegetative biomass has three major effects on soil movement. First, the canopy structure gives rise to the aerodynamic roughness of the canopy, which determines the friction velocity at the top of the canopy for a given windspeed. Second, leaves and stems deplete a portion of the friction velocity through the canopy and, thus, control velocity near the surface. Finally, if the surface friction velocity exceeds the threshold, vegetation intercepts some of the saltating particles in flight to further reduce soil movement.

Flat residues are treated both as creators of protective surface cover, and as sources of surface roughness. Thus, flat residues modify aerodynamic surface roughness, protect part of the surface from both abrasion and emission, and may enhance surface trapping.

The EROSION submodel data base will consist of the descriptors necessary to delineate the simulation and accounting region boundaries. It will also include information on barriers and hills. Most of these inputs will be generated by the user.

VALIDATION

The submodels will be validated using various methods. The weather series generated by the WEATHER submodel will be compared to actual weather time series to ensure that both produce similar statistical parameters. Using recorded meteorological variables, the temporal soil properties predicted by the SOIL and TILLAGE submodels will be compared to measured soil properties in plot studies. Similarly, biomass production patterns of some major crops will be compared to biomass production predicted by the CROP submodel.

Finally, the EROSION submodel will be validated by instrumenting a series of field-scale sites. This appears necessary because development of the equations describing the erosion subprocesses is being done in laboratory wind tunnels for individual subprocesses. In the field, the subprocesses are combined and operate over larger scales than in the laboratory. An initial field-scale validation site is in operation at Big Spring, Texas; and other sites are planned near Sidney, Montana; Walsh, Colorado; Alliance, Nebraska; and Malden, Missouri.

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