SCIENTIFIC INPUT FOR SOIL MANAGEMENT MODELLING

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FORWARD

The Alberta Soil Science Workshop is held annually in conjunction with the Alberta Soils Advisory Committee meetings. In 1974, the theme of the Workshop was the

"Scientific Input for Soil Management Modelling".

The program was intended as an "integrated brainstorming" session to consider the manipulation necessary to create ideal soil conditions from five aspects: Meteorology, Classification, Chemistry, Microbiology, and Physics. The papers were broad in scope, covering information-gathering systems to the final model used in providing practical agronomic information to those in the farming business.

The Workshop Committee would like to thank the authors for their papers, and those who participated in the Workshop discussion.

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METEOROLOGICAL INPUT IN SOIL MODELLING

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I am sure you are all aware of the important part that meteorological variables, or climate, has played in the formation of the soils of Alberta, and that climate is the major factor determining what crops can be grown in a region. Climate cannot therefore, be omitted from any model trying to interpret plant development.

Properly developed models can be used to:

- assess land capabilities, and the range of adaptibility of crops,
- predict yields and earliness of maturity,
- identify the major factor limiting plant development in each area, and
- identify superior genotypes for each region.

The difficulty is going to be to identify the variables which need to be included in the model, and I will try to point out some of the problems and limitations which have arisen from previous models due to too few variables or projecting results of limited observations.

Modelling is not new. The first suggestions of a meteorological model for plant growth was made 240 years ago (Réamur, 1735) when it was suggested that the sum of the mean daily air temperature was constant for a particular species of plant. It was, however, another 100 years before the suggestion was considered again, and degree-days were used to calculate ripening of grain (Bausingault, 1834). Another fifty years later the number of hours of day light was added to the model (Tisserand, 1875).

These earlier models had limited application but were, and still are, often broadly applied and hence have led to considerable misunderstanding. For example, simple heat-unit and degree-day concepts work quite well for identifying earliness of maturity in an area where all factors affecting plant development except temperature are fairly uniform. However, where one or more of the other factors vary the simple models do not work. For example the relative heat-unit requirements of corn genotypes in Ontario are different to Manitoba, and in southern Alberta to northern Alberta etc., similarly, it takes less degree days to ripen wheat at Fort Simpson than at Beaverlodge, and at Morden less than at Lincoln, Nebraska, etc. Despite these limitations I am frequently told by agriculturists that we do not have enough heat units based on requirements for other regions to mature specific crops in the Peace River region.

In the past 35 years, and particularly the last 25, a considerable volume of literature has arisen with various modifications and additions to previous models. The concepts of threshold values, base lines, upper and lower limits, optimum values, photoperiod, thermoperiod, altitude, latitude, potential evaporation and evapotranspiration etc. have been introduced.

Not only have the type and number of meteorological variables been changing but also the period of time over which the variables were related to plant responses. Early models were based on annual, or monthly totals or means. The more sophisticated models use daily and even hourly values, and recognize that base, optimum, and upper limits of many variables change with phenological development. These concepts must be considered in any model trying to relate climate to plant development.

When we talk about meteorology we normally only consider the air, but soil moisture and temperature are just as important, especially during germination.

Before going further into soil temperature and moisture I would like to briefly outline the results of an experiment carried out by Dr. Al. Carder. I will be referring to the results from time to time.

After some preliminary observations Al. established test sites at two locations, 11.3 kilometers apart and differing in altitude by 238 metres. Soil and other management practices were standardized and the sites so situated that there was no difference in exposure to sun or wind. Thatcher wheat was grown at both sites for three years; one year was a particularly cool year, another above average, and the other intermediate. In all three years the wheat in the valley was earliest and produced the highest yield. The only consistent difference between sites was the maximum air temperature and the air thermoperiod during the emerge-to-4-leaf and soft dough-to-ripe stages, and the mean minimum and maximum soil temperature during the seed-to-head stage of development. These results bring into question the value of mean and minimum air temperatures, and degree days for assessing earliness and yield.

It was found that 50 to 67% of the difference in earliness was due to maximum temperatures during the soft dough-to-ripe stage of development, and the difference in yield was probably due to soil temperatures. Other studies support these findings.

Let me now return to the soil temperature and moisture uses in models of plant development.

Soil temperature and moisture are the only climatic factors important during seed germination. In some areas temperature is the main limiting factor whereas in other areas poor moisture conditions are more limiting than temperature. Soil temperature and moisture are also important during the early stages of growth, and probably during the entire growth period since they have pronounced effects on mineralization and the soil micro-organisms.

The first model that I am aware of which included soil climate was published by Williams and Robertson in 1965. This model included a spring soil moisture variable which was derived from the precipitation of the previous months without any apparent consideration of the amount of moisture that was absorbed. Likewise, subsequent models which also included precipitation after seeding, appear to have assumed all precipitation was absorbed by the soil. I have yet to see a model which included soil temperature despite its importance during germination and the early phases of plant growth.

There is little doubt that the climate above the ground is the major factor determining the climate in the soil, or that characteristics of the soil affect the amount of heat and moisture absorbed. But:

- Do we know enough about the differences in absorption in all soils under all conditions to assume that the differences are not important and hence air temperature and precipitation can be used instead of direct soil measurements?
- What are the differences in temperature and moisture absorption in different soils?

- Are the differences great enough to merit consideration in a model? In Carder's study up to 4°C differences in soil maximum air temperature and 3°C difference in minimum and mean temperature had no effect on earliness of emergence, or length of emerge-to-4-leaf stage.
- How long do soil temperatures affect plant development? In several experiments where soil temperatures were recorded we found that the differences between treatments was greatest in early spring, and decreased and finally disappeared as spring and summer progressed. In Carder's work mean, maximum and minimum soil temperatures were significantly higher in the valley up to anthesis during the cool year but only up to the 4-leaf stage in the warm year.
- Does a similar reduction in soil temperature occur in the different soil types?
- Do we know the relative importance of maximum, minimum and mean temperatures in plant development? In Carder's study minimum soil temperatures were highest during the soft dough-to-ripe stage at the latest and lowest yielding site. Since there was no differences in mean or maximum soil temperatures this indicates that soil temperatures are not important during ripening. Somewhere along the growth curve soil temperatures appear to lose their relative importance. Do we know where?

Similarly, can we derive the amount of water available to the soil from precipitation? Not all precipitation is absorbed and retained in the rooting zone. Some is lost in run-off and some penetrates below the rooting zone. The amount lost by run-off depends on the slope and the surface condition of the land, rate at which rainfalls or snow thaws, the

permeability of the soil due to frost, pore size, etc. These factors will have to be considered in a model.

- Do we know enough about the absorption of precipitation in different soils under different conditions, or how much of the absorbed moisture can be used by the plant?

We talk quite knowledgeably about field capacity and wilt point but:

- Do we really know what the upper, lower and optimum moisture conditions are for plant growth?
- Does the field capacity and wilt point have a direct bearing on plant growth or are they primarily physical characteristics of the soil?
- Should the moisture variable be suction and if so do we have sufficient knowledge to apply it?

It would be much easier and more accurate to measure soil moisture directly if suitable instruments were available. But if we can determine soil moisture accurately do we know enough about the moisture requirements of plants at all stages of their development. We know moisture is essential during germination and the early stages of plant growth, but: Is moisture needed during ripening or is moisture detrimental at this stage?

I do not know the answers to the above questions and have probably shown my ignorance. However, before others also show their ignorance by saying they know all the answers let me again remind you of the limitations on the use of models using too few variables (for example heat-units) and also bring to your attention some problems which have arisen, or can arise,

by developing models based on conclusions drawn from inadequate data and projected.

1. Four individuals, three from maritime climates and one from the hostile climate of Ottawa concluded that the minimum temperature during the winter was the major factor causing winter injury in woody shrubs. Researchers using a designated group of genotypes, and, by projecting the above observations, drew plant hardiness zones for all shrubs in all areas of Canada. In the North, and I suspect in many other parts of the prairies, it is the fall and early winter weather which determines the amount of injury. We do not know precisely what factor it is but we do know that any shrub which is not injured by Christmas is usually not injured by the minimum temperature in January. All the zonation maps show are the range of adaptability of the genotypes studied, but in the case of the North for the wrong reason.
2. The concepts of photoperiod and thermoperiod have been and still are widely accepted and widely projected despite literature which shows limitation to their application. These have not yet been used in models but the concepts have been so widely accepted that they cannot be ignored in models of some crops.
3. Similarly, it is generally accepted that winter injury to trees and shrubs can be reduced with irrigation just prior to freeze-up. The data upon which this recommendation is based appears to be two, more or less casual, observations on fruit orchards in the Okanagan. This recommendation assumes that the moisture reaches the root zone, has

been absorbed by the roots, and that injury is due to dessication. I doubt that this recommendation applies in many parts of the prairies.

Another common practice to avoid is to assume that a model developed for one, or a few, genotypes is applicable to all genotypes of the crop. Genotypic differences in response to threshold, optimum and upper limits of many variables are the very basis of breeding and selection of new cultivars and it is difficult to understand why genotypic differences are ignored in models. By not recognizing these differences the usefulness of a model is limited. For example, Olli barley will grow on soils of higher acidity than other barley cultivars, and thus the pH threshold, optimum and upper limits must be included in the model. A model developed for Olli barley would not be a suitable model for other barley cultivars since it would show a much wider range of suitable soils than most cultivars can tolerate. Similarly, a model built on barley cultivars other than Olli would show a restricted range of adaptability.

To summarize:

It is doubtful whether we know enough about plant development under all conditions to develop a universally workable model. However, by developing models, testing and modifying them useful models will gradually develop. We must, however, first:

1. Understand what the model is to show (e.g. earliness or yield) and that there are limitations to its use.
2. Realize that soil moisture and temperature are not determined solely by precipitation and air temperature but also by characteristics of the soil.

3. Realize that while soil climate is of prime importance during germination its importance relative to air climate gradually decreases until it is doubtful whether it has much if any effect on ripening.
4. Realize that many generally held concepts (e.g. cause of winter injury, thermoperiod and photoperiod) have limitations and cannot be projected to cover all conditions.
5. Realize phenotypic differences in all crops.

Literature Cited

Réamur, R. A. F. de 1735. Observations du thermometre, faites a Paris pendant L'anne 1735, comparees avec celles qui ont ete faites nos isles de l'' Amerique. Paris Memoirs, Acad. Sci. Cited in Meteorological Monographs; Recent studies in Bioclimatology 2:1-3 Amer. Meteorological Soc. 1954.

Bousingault, J. J. B. D. 1837. Economic rural consideree dans ses rapport avaec la chimie, la physique et al meteorologie, 1st, ed. 8^{o} Paris, Cited by Abbe (1905), p. 73.

Tisserand, E. 1875. Memoire sur la vegetation dans les hautes latitude, P. 271. Memoires de la Societe Centrale d'Agriculture. Cited by Cleveland Abbe (1905), p. 73.

Williams, G. D. V. and Robertson, G. W. 1965. Estimating most probable Prairie wheat production from precipitation data. Can. J. Plant Sci. 45:34-47.

SCIENTIFIC INPUTS FOR SOIL MANAGEMENT MODELLING - CLASSIFICATION AND PEDOLOGY

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Cline (3) in 1961 stated that the success of a teacher depends to a high degree upon his ability to create in the minds of his students an integrated model of his subject as a whole, in contrast to an agglomeration of concepts of its constituent parts.

I think this philosophy may be applied to the subject we are discussing today, namely "Scientific Inputs for Soil Management Modelling". Perhaps to this time we have been looking at soil management modelling in the context of its constituent parts rather than as an integrated model of the subject as a whole. Certainly, soil management involves much more than pedology alone or soils chemistry or physics. Therefore, hopefully our discussions today will serve to create an awareness among us regarding the constituent parts and the integration required for modelling.

It is interesting to note that in his discussion of soil modelling, Cline suggests that a model is not real and that in time research will prove it wrong in whole or in part. Ultimately each model destroys itself through the studies it inspires, which in turn, create a new or modified picture better than the old. However, it is probably somewhat premature at the present time to be overly concerned with the destruction of a model that is not as yet that well defined.

Two sets of forces determine the most profitable cropping system for a farm - firstly, the physical considerations of climate, soil and topography, and secondly, the economic considerations. Obviously we are only dealing for the most part with the first set of circumstances today, but it should be emphasized that the best management system cannot be selected with only one type of information.

The pedologist or soil classifier is responsible for the geographic aspects of soil distribution. If we accept the premise that all soils do not respond to the same type of soil management then soil classification becomes one of the constituent parts of the soil management model.

The general purpose of soil classification has been stated in a variety of ways, one of which is (2) "to organize and synthesize the knowledge of soils so that it can be remembered and communicated and so that relationships among soils and between soils and environments can be seen". Perhaps the important point in this definition is that of communication. To be of maximum value the concepts of soil classification, and soil mapping must be interpreted in such a manner so as to be understandable to the man ultimately responsible for soil management -- the farmer.

The Canadian system of soil classification, like most systems, is a hierarchial one in which the classes are conceptual based on the generalization of soil properties. Classes are defined on the basis of observable and measurable soil properties that reflect real processes of soil genesis and environmental factors. The system is not perfect, and is subject to change as more knowledge of the soil becomes available. Despite its imperfections, the system does allow us to: assign the soils throughout Canada to classes at various levels of generalization, define the kinds of soils that occur within units on soil maps, and provides a basis for evaluating mapped areas of soil for a variety of potential uses.

Basic to the use of pedological information for management modelling is the taxonomic level and map scale at which information is completed and presented. In terms of Taxonomy, fewer and less precise assertions can be made as one progresses from the more detailed (series) to the more general (great group) categories. Therefore, where soil management at the farm level is concerned, it is desirable to have the soil classification at a detailed level of abstraction.

At the same time, presentation of the data at an appropriate map scale is important. For example, at a scale of 1:15,000 (1 mile = 4 inches) the smallest size of area that can be shown cartographically is about 6 acres, whereas at a working scale of 1:125,000 (2 miles = 1 inch) the minimum sized area is 300 acres. Obviously, at this latter scale, considerable information significant to soil management could not be shown on a map of such a scale.

Given a soil map of adequate scale, the next step in modelling would be to interpret the data in terms of management units so that the soil taxonomic units can be grouped into a manageable number. This has been done in the midwest United States where the management units were set up by a committee composed of representatives of the production and marketing administration, the county agent, representative of the Research Station in the area, a farmer representative, and a pedologist responsible for soil mapping in the area.

An attempt to carry out such a study was initiated in the Peace River area of Alberta and British Columbia some 15 years ago, but unfortunately, I think, allowed to "die on the vine". In this case, the term "agronomic groupings" or "family groupings" was applied to the management groups. In creating the agronomic groups the soil characteristics considered were those that affect moisture relationships, fertility and tillage, namely texture, permeability, organic matter content in the surface six inches, natural soil drainage and stoniness. Such groupings were further subdivided if necessary on the basis of slope, degree of erosion or soil reaction. This type of grouping provided for natural combinations of many soils into a convenient number of units, which expressed the main differences in productivity and so were useful as the basis for land evaluation.

More recently, in Canada we have completed a soil capability for agriculture classification system. The capability groupings provide information at two levels of

generalization, namely the class and sub class. Soils maps are interpreted into seven classes; Class 1 soils have the greatest number of alternatives and Class 7 the fewest. When uses are considered collectively, the risks or limitations become progressively greater from Class 1 to Class 7 land.

Capability sub classes within each class denote the major kind of conservation or management problems. Four kinds of problems are recognized in defining sub classes: (1) Run-off and erosion; (2) wetness and drainage; (3) root zone and tillage limitations, such as shallow soils, stones, low moisture holding capacity and salinity; and (4) climatic limitations.

Ideally, therefore, from a pedological standpoint, it would be desirable in farm management modelling to characterize our interpretative soil groups in terms of the subjects we are discussing here today -- soil chemistry and fertility, soil physics, soil microbiology, soil biochemistry and tillage practices. An important and long-standing challenge to agronomic research is the need to determine the nature of the productivity potentials for particular soil types or soil groupings.

In summary, therefore, pedology or soil classification is one constituent part of the model for soil management. The other parts include soil fertility, management and soil-plant relationships. Workers in these fields have an important relationship to and contribution to make to interpretative grouping of soils, to productivity ratings and to providing yield estimates under different systems of management. With over 450 different soils mapped in the province it is obvious that field experiments can be conducted on only a very small percentage of these soils. However, if principles of soil-crop relationships are developed and their quantitative significance obtained for key soil types, then by extrapolation yield estimates can be made for other soil types of known properties. Without question, much of the required informa-

tion exists today, it is a matter of assessment and collation in terms of soil management modelling.

Finally, I think it is interesting to note and perhaps something to keep in mind, that Aandahl (1) states rather affirmatively that in the U.S.A. it is now recognized that the function of the natural or social scientist is not to make decisions on soil use and management. More and more they are recognizing their function as one of providing information about soils and the alternatives in use and management rather than making decisions for someone else. Choices are made by the farmer or ranchers themselves as to alternatives best suited for a given set of circumstances.

REFERENCES

1. Aandahl, A.R. (1958). Soil Survey Interpretation - Theory and Purpose, Soil Science Society of America Proceedings Vol. 22, No. 2, 152-154.
2. Canada Soil Survey Committee (1973). Proceedings of the ninth meeting of the Canada Soil Survey Committee, Saskatoon, Saskatchewan.
3. Cline, M.G. (1961). The Changing Model of Soil, Soil Science Society of America Proceedings Vol. 25, No. 6, 442-446.

SCIENTIFIC INPUTS FOR SOIL MANAGEMENT MODELING

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Soil Chemistry and Fertility

My first reaction to being asked to make a presentation on the above topic was one of dismay. The reason for this reaction was the nebulous nature of the topic for soil management is a segment of an even more nebulous term--farm management. After considerable thought I decided that the exercise might be beneficial because over the years there has not been sufficient attention devoted to soil management. When my father settled at Kindersley, Saskatchewan in 1906, he didn't have many soil management options at his disposal. Fertilizers, weedicides and pesticides were unheard of in that district in those days and the choice of tillage machinery was very limited. Today, the situation is vastly different and farmers have to make many decisions on all phases of farm management including soil management. During the past 50 odd years a tremendous volume of scientific data has accumulated in the form of scientific articles and other printed material. The Soil Survey reports for example have a great deal of information on the physical and chemical properties of soils together with descriptive material on climate and cropping programs for the area covered by the particular report. Researchers and extension personnel have reworked some of the scientific data and published many bulletins and pamphlets for farmer use. Certainly, the Soil Testing Services that are available in most Provinces of Canada have assisted the farmer in making soil management decisions and have undoubtedly led to improved productivity of soils. Soil pH and base saturation are two chemical properties that have proved particularly useful in combating soil acidity problems by aiding in the proper selection of acid tolerant crops and by determining the need for lime. One could go on and on citing examples of where the use of chemical properties have had a substantial impact on soil management.

The foregoing comments might leave the impression that there are no problems and of course such is not the case. In my view, the factors influencing soil management can be divided into three broad categories: soil data accumulation (data bank): model building and data evaluation; and data transformation for farmer use. The latter consists of organizing the data in a format that can be understood by the farmer and in a form that will permit him to readily incorporate the information into his soil management decisions. Of the three categories, the first (data accumulation) is the most active and in fact the literature is extremely voluminous. The second phase (model building and data evaluation) is progressing rather slowly, in my opinion, and I believe more effort has to be directed to this area. At this point I wish to quote a document entitled "Status and Methods of Research in Economic and Agronomic Aspects of Fertilizer Response and Use, p. 35" for I believe it puts the term modelling into perspective:

> Considerations of a statistical nature enter into the planning of response surface experiments in: (1) Selection of an appropriate functional model to mathematically characterize or approximate the surface, (2) Selection of the treatment combinations that will permit characterization of the response surface with minimum variance and bais (the treatment design and plan), (3) Selection of type of blocking

> arrangement or field layout for assigning these treatments to the plots (the experimental design), and (4) Allocation of experimental resources to the number of replications and the number of sites and years required to sample satisfactorily the environment-season complex of the population of farms about the predictions (experimental inferences) are to be made. The primary function of the statistical analysis of the resulting data is to provide the estimates of the parameters for the chosen functional model, along with some measure of precision of the estimates of these individual parameters, as well as some measure of the goodness of fit of the overall model to the data.

The research involved to satisfy the foregoing is time consuming and costly, however, increased computer services in recent years have greatly aided in the type of sophisticated research that is required. We have reached the stage where scientists know fairly well in a qualitive way the input factors that are important in crop growth and soil management. In the years ahead we must devote more attention to quantifying these input factors. Undoubtedly, new techniques will be found that will aid in the quantification of the soil data and as a result some of the soil data now on file will be discarded as being useless and additional data will be generated. The chemical, physical and biological properties of the soil together with climatic factors simultaneously affect yield. Consequently, in order to obtain maximum results they should be studied simultaneously in the modelling process. Finally, if modelling is to be of maximum assistance to the farmer the effects of the input data on yield and soil management should have been evaluated previously (phase 2 data evaluation) and in quantitative terms. This evaluation may be very complex because of the multiplicity of input factors that affect yield as illustrated in the enclosed figure. However, there are techniques for simplifying the model and I wish to illustrate this by discussing a study that I have been associated with for the past 10 years, where we have related the yield of barley and forage to several independent variables. We reduced the number of input factors (depicted in the figure) by grouping factors and making use of sub-routines in the analysis. For example, nearly all the weather factors listed in the lower half of the right hand column in the figure were used in a sub-routine to determine the stress days in various physiological stages of growth of the plant. Thus, all these factors were reduced to a single stress day factor that was inserted into the regression model. Also, many of the soil physical factors such as wilting point, field capacity etc., were used in the calculation of the stress days. We are currently working on a model to include root impedence for it too is an important factor. We assigned a dummy value to each soil order for inclusion in the model for we realized that there are many important soil properties that were not accounted for in terms used. There is great scope for improving this aspect of the model. Also, the nutrient status of the soil was evaluated by including soil test values in the model.

The remainder of my paper will deal with the third phase, that is data transformation for farmer use. The key person in soil management is the farmer, as already mentioned, for it is he who ultimately makes the choice and

I hope this will always be the case. In our free enterprise system, the farmer is given the opportunity to exercise his skills and judgement. One often hears the question asked as to why a particular farmer does very much better than his neighbor--both farming the same soil type. Usually it is a difficult question to answer and no doubt timeliness of tillage, type of tillage, proper use of fertilizers, proper weed control and a whole host of factors included under the term farm management are responsible. Now comes the crunch! I wish to quote from an article "Co-operative Research on Input/Output Relationships in Use of Fertilizers in Crop Production. Organization for Economic Co-operation and Development. Paris, 1966, p. 27".

> Broadly speaking crop yield is controlled by soil, climate and weather, soil management and genetic constitution of the seed. While the genetic constitution of the seed is constant the soil management factors are determined by the skill of the farmer and the technical equipment available---the farmer is influenced by his knowledge of the soil and climatic conditions. The skill of the farmer is undoubtedly a very important factor in determining the final yield. However, since it is difficult, if not impossible, to estimate the effect of this factor quantitatively, randomization seems to be the best method for eliminating it. The farmer's skill is thereby dropped from the discussion.

The foregoing gives the view of a group of Swedish Scientists and illustrates the difficulty in evaluating quantitatively the input by the farmer. One could argue that there is little point quantitatively evaluating one portion of the yield model if some portion such as soil management remains unquantified. I suppose one approach may be to develop yield models for low, medium and good management levels but here again the terms are difficult to define and brings me back to my opening comments regarding the nebulous nature of the term soil management. I think more effort should be directed towards quantifying this term.

My concern is that no matter how good the data bank might be, or how well the data have been evaluated for yield and soil management practices, the whole program will fall short of expectation if farmers do not put the data to use in their operation. How well have we assisted the farmer in this step? He can no longer be content with a general recommendation for he is concerned about the growth of a selected crop on a given soil under a specific set of soil moisture and climatic conditions. It may be that the soil data presented in bulletins were collected under a different set of conditions to those existing on a particular farm. How can the farmer be expected to extrapolate, interpolate or adjust the data to suit his requirements. This is a difficult problem to solve and certainly I don't have the answers. However, I believe it is the weakest link in the whole modelling process and a great deal of effort will have to be expended to bridge the gap. Twenty-five years ago when I joined the Canada Department of Agriculture I frequently heard the complaint, on the part of researchers, that farmers were not making adequate use of their research data. I hear the same complaints today but I submit that the farmer is not entirely at fault for often the data is not readily available to him and in an acceptable form. The Alberta Institute of Agrologists was sufficiently

concerned about the problem of technical assistance for the farmer that the Government of Alberta was asked to fund a study. Out of this request, grew the study "Tradition and Transition. Extension Education for the Farm Unit in a Changing Society" dated December, 1970. Chapter 4 item 7 is entitled, "Our dialogue with farm unit operators and their wants", provides interesting reading. I don't know what impact this report has had on Government policy but I was told recently that District Agriculturists are being swamped with administration and thus have less and less time to spend on the extension of research to practical use. This suggests that the farmer is being more and more alienated in this respect and left to cope on his own, thereby decreasing the possibility of him putting more research data into practice.

To end on a positive note, I don't think it is unrealistic to suggest that a goodly portion of the chemical, fertility and other soil data that we now have at our disposal be placed in a suitable data bank. Programs should be devised by scientists whereby farmers and extension personnel could, by asking appropriate questions, obtain specific information that will be applicable for a particular farm operation. I heard recently that the cosmetic industry uses this approach to good advantage in aiding clients to select suitable facial materials. Surely, the farmer would benefit from a properly designed and operated data bank which could be revised, updated and improved upon over the years. This would allow the farmer to make better use of data that has stood the test of time. Over the years, other data will be generated and evaluated through the modelling system.

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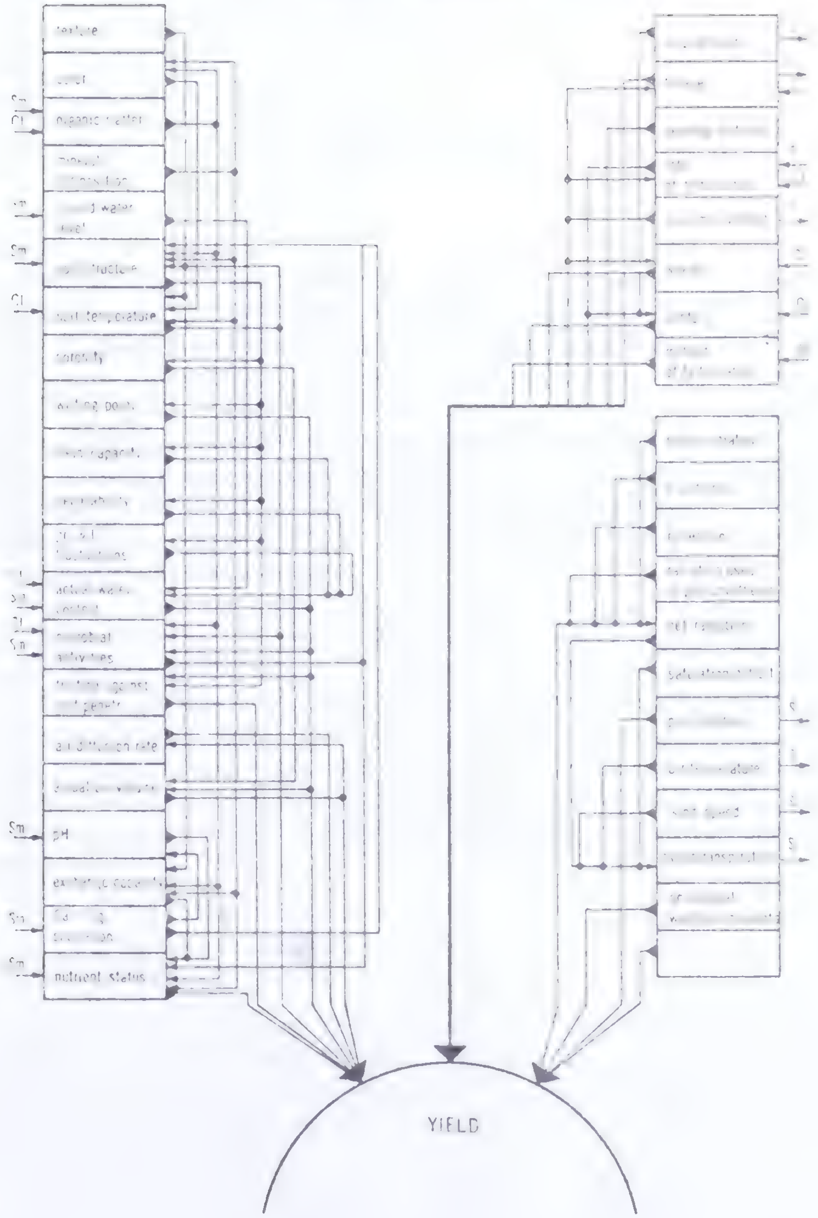
Figure 2.2. Factor scheme



Soil, Systems Analysis, Modelling, Management
and the Microbe

by

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INTRODUCTION

Modelling is only one part of the whole-system approach necessary in management of soil. Systems analysis arose in Engineering because various disciplines were unable to communicate with each other effectively. There is a tremendous need for the same approach in Soil Management, and for the same reason. As a system becomes more complex, the need for a systems analysis approach to its management increases. Generally the difficulty and work involved in using a systems analysis approach increases as the system becomes more complex. Soil-plant systems are very complex. The advantage of a systems analysis approach is that it allows soil managers and researchers to simplify these complexities.

In this paper I will deal with the microbiological and biochemical aspects of the situation. The place of models in this approach will be briefly mentioned as will different types of models. The use that can be made of our present data pool and the areas where data are missing will be enumerated. The type of data we need will be further expanded on in terms of kinetic approaches to biological events in soil. The paper will conclude with a general overview of the present types of models presently developed and their use.

A. Systems Analysis

A "system" may be defined as an "interlocking complex of processes characterized by many reciprocal cause-effect pathways" (Watt, 1966). A system must be managed as a whole. Systems analysis is therefore a collection of techniques and theories for studying and managing interactions between the various parts of a whole.

Several aspects in addition to modelling are included in this approach:

1. Determine which variables affect the system.
2. Determine the structure of the system.
3. Description and development of a model to describe or control it

pertinent information about the structure and function of the system.

4. Simulation of the system to determine how it can be managed to produce optimal results.

We presently have a lot of information on the structure of soil plant systems and on the variables affecting them. We lack data on function. Models will be useful in pointing out the type of kinetic or functional data to collect and how to use what we have. They will also provide the mechanism to tie together the data already collected and will allow soil physicists and soil microbiologists, for example, to communicate with each other.

B. Models

For purposes of soil management, the model is only a tool used to help make decisions about action to take to achieve a particular goal. It will help reduce the cost of field experiments but it will never replace them. The model may be in the manager's head or it may be complex, making its storage on paper or in a computer necessary. Models may be static or dynamic. Dynamic simulation models will be the most useful in the long run but will take a long time to develop.

Resolution of the model is a characteristic which, for biological systems, can be manipulated by the user and developer. The resolution (time scale or precision) depends on the purpose of the model and on the understanding we have of how the system operates. Most management models in use now are of low resolution for two reasons. First, they are more generally applicable, but therefore less site-specific. Secondly, the whole soil system may be too poorly understood at present to allow higher resolution. Use of these models must be restricted to large area generalizations.

Three broad resolution groups may be delineated for soil biological use:

1. Macro-level

    - only major groups of processes and functions are included
    - very empirical with a low level of resolution
    - e.g., yield correlation with added N; N mineralization over a number of years correlated with total organic matter content.
    - useful over a wide range of soils

2. Semi-micro-level

    - combines many individual processes: leaching,

denitrification, erosion, nitrification, humification, mineralization, immobilization. Uses a large body of background information of many types. The whole soil is usually still considered.

- it has fairly high resolution and is reasonably site specific.
- Can be used by managers and also by researchers and may be the logical link between the two.
- It can not yet be used widely because we lack much of the necessary quantitative information on soil dynamics.

3. Micro-level

- single nutrient in detail
- complete soil system not included
- may be further subdivided into individual reactions
- subdivision produces high resolution but the output is of limited practical value by itself.
- this type of model may be part of larger models for the whole system.

C. Data Needed for Modelling

1. Qualitative information

i) Chemistry of organic materials in soil. This information is not directly incorporated into the model but is essential for two reasons. First to provide an accurate understanding of system structure (e.g., what is the CEC of various types of humus, what buffering capacity has it, how is it formed, what processes are involved, what plant or microbial components are involved, etc.). Without this information, how the system really works will not be known and models for soil management developed without it will be correspondingly very general. We still lack some of the information needed here in terms of mode of formation, reactivity and what significant qualitative differences are there between soils. The second reason this data is necessary is to provide the manager and researcher (as they construct the model together) the necessary background framework and concepts needed to make rational decisions about the system worked with. This background information will allow the manager to make reasonable and rational assumptions and to know which corners can safely be cut.

ii) Chemistry of inorganic materials in soil and their biological oxidation and reduction. This information is absolutely necessary to development of the structure of the system. It is necessary to have this information to know how for example, various management practices affecting aeration might alter soil NO_3^- or $SO_4^=$

levels. Much of the information needed here is already available. Some gaps still exist in understanding which parameters are of most importance in controlling these events. Many of the real gaps will be found only when we start compiling and organizing information for models.

iii) Effect of soil environmental conditions on soil processes and vice versa. Soil pH for example influences nitrification, nitrogen fixation, etc. We must have an accurate catalogue of what these effects are to develop the structure of the system. Some of this type of information is lacking. There is an even greater lack of information on the effect of soil biological processes on soil environmental conditions. The effects of management practices such as use of pesticides and fertilizers on soil biological activity have not yet been fully examined. In the area of N fixation, we are still a long way from truly understanding which soil conditions are most suitable for either symbiotic or nonsymbiotic fixation. The effect of using legumes in soil rotations is still poorly understood in terms of their effects on soil properties such as pH, structure, organic matter contact, moisture regime and even total N level.

2. Taxonomic Data

i) Specific Transformations. It is from this type of data and these studies that the pathways of many soil processes are elucidated. Again we need this information in developing the structure of the system although much of it may not be directly incorporated into the model itself. Taxonomy cannot be modelled.

ii) Disease. Information in the area of pathology is still deficient in terms of factors controlling extent of yield depression by a given infestation and what controls the degree of infestation. We have a fairly good idea now about the organism but I wonder if we have enough quantitative information on the factors controlling various parasitic problems. Certain problems in the area of pathology are the production of toxins during decay of organic residues in soil. This will not likely be obtained from taxonomic studies but from more general decomposition studies.

iii) Fixation. Taxonomy as it relates to N fixation in soil has been widely studied but (I think) many gaps still exist here, especially in terms of N fixation in the rhizosphere, by mycorrhiza and in nodulated non legumes.

iv) Organism interactions. Many of these have still to be elucidated. Some have been mentioned earlier (rhizospheres, mycorrhiza, pathology, etc.), but the interaction of soil animals and soil microorganisms is still obscure. The role of soil animals in N mineralization processes requires further work. At present there is a large gap between the concepts held by soil microbiologists and soil zoologists. We do have a large body of information here though and can develop enough of the structure of soil systems in this area to produce high resolution models.

3. Quantitative Information.

This is the real gap. This area contains less than 10% of the information necessary. We need two types of quantitative data. They are data on soil state variables and on reaction or process kinetics. The former is useful for developing structures and we have a lot of it. We are going to find though that we have a tremendous pool of the wrong information on state variables when we start developing and using models. Kinetic data in good usable form is almost nonexistent. We do not know, for example, the effect that NO_3^- concentration has on rate of denitrification. We are in the dark on the actual rate of nitrification although thousands of papers have been written on the subject. We know nothing meaningful about rates of N fixation, of S transformation, organic matter breakdown or of the factors that really control them in soil.

Most of the good quantitative information is contained in the literature from at least 30 years ago. The present literature has become increasingly loaded with purely qualitative data, or else state variable data, as a result of the proliferation of "black boxes" and of "black box techniques" and approaches. Electronic gadgetry has done nothing to provide the quantitative data that we need, although the potential for it to be used to this end is phenomenal. One reason for this is that the term "basic research" has in the last twenty years been appended to the qualitative efforts. Studies with rigorous measurements of reaction rates in soil and the quantitative evaluation of the simple things that affect them like moisture, temperature, pH, etc., has been considered too mundane, "general" or "applied". The academic elite (both Government and University) has preferred to think they were doing "basic" research. Recently an interest in quantitative work has been developing because of the availability of computers and their apparent respectability in academic circles. We may now be starting to do the right thing but for the wrong reason.

There is a crying need for good solid quantitative data. For data that will have application to more than one situation on more than one soil. For example, we know [Al] is related to texture, pH and minerology, but do we know what the relationship is? Do we know how rapidly [Al] will change in a soil if it is being acidified by fertilizer application or S oxidation? We must if we are to make long term predictions. We must be able to make long term predictions if we are going to effectively manage soil. We are still too much in the dark in areas of the persistence of organic pollutants in soil for example. We know what most of the factors controlling this are, but we are very sorely put to give practical answers to practical problems in these areas. We need quantitative data if we are to provide these answers. Admittedly when an organism, a chemical or a chemical reaction escapes from the test tube to the real world, we are faced with a multitude of complexities. We must be willing to face them and competent to handle them. Quantitative kinetic data is necessary to do that. We will very likely not get that data while the present categories of "basic" or "applied" are bandied around with such reckless abandon. Basic research so often restricts

itself to qualitative affairs. Applied research must defend itself by being immediately applicable, this results in its being empirical and the quantitative aspects of it not as generally useful and applicable as they should be. Research is not very basic if it is not basic to anything or cannot eventually be generally applied. Much of our present basic research cannot now, and likely never will be, applied. Research is not very practical or applied if it must be repeated for every new soil or situation. Modelling will help a lot in bringing together these various types of data and in providing a framework in which they can be applied.

D. Kinetic Approaches to Getting the Data Needed

1. Half life

Growth or loss of substrate in a system in which the rate is a function of the variable itself is termed an exponential change. These first order reactions (rate is a function of the concentration of one component) when applied to situations of decay have been assigned a half life as a way of expressing the rate of loss of substrate. The half life of a substrate undergoing exponential loss can easily be calculated. A plot of the log of concentration vs time gives a straight line for first order reactions. The decay rate k can be calculated as:

$$k = \frac{1}{t} . \ln \frac{Ct}{Co}$$

where t = time lapse

ln = natural log

Ct = concentration at end of incubation period

Co = concentration at beginning

k = change in concentration per unit of substrate per unit of time.

From the decay constant, half life can be simply calculated as:

$$t\ 1/2 = \frac{0.693}{k}$$

2. Turnover Time

Another useful constant is the turnover time. In some cases (soil organic matter at equilibrium) the quantity of metabolite remains constant due to degradation and resynthesis at the same rate. The turnover time is thus the time required to metabolize the total quantity of metabolite in the system. It is also calculated from k as:

$$T_{1/e} = 1/k$$

k = decay constant

$T_{1/e}$ = turnover time

The half lives of plant residues in soil and of soil organic matter have been measured for a few situations. For example the half life of immobilized N in two Saskatchewan soils was 3.5 years during the first 3 year period after adding fertilizer N, with a turnover time of 5.1 years (McGill, 1971). A large pool formed by continuous fertilization and straw return would release about 20% per year. Therefore the larger this pool is the better the N supplying power of soil will be since this is the most readily available soil N. Summer fallowing tends to destroy this pool.

Many farmers have observed that soils with the straw returned for a number of years are more productive than those in which this is not done. The above data provides a quantitative explanation for it and a management tool or simple model that can be used fairly directly.

The half life of N in straw added to two Saskatchewan soils was 2.3 years for a Grey Wooded soil and 3.0 years for a Brown Chernozemic soil (McGill, 1971). The corresponding turnover time for straw-N added to these two soils is 3.3 years and 4.3 years. In a cropped Grey Wooded soil, 30% of the N added as straw per year was remineralized, whereas in the Brown soil studied 23% was remineralized per year. Although only 23 - 30% of the N added as straw was remineralized per year, the added straw readily decomposes, and in one year very little of the N remained as recognizable straw particles, most of it was converted to microbial tissue or remineralized.

These data are useful but have one major deficiency. There is not enough data to know whether the values so obtained are applicable to a wide range of soil conditions and how the turnover rate would be affected by changing soil conditions.

Expressions of half life as used above provide good information but they also average a lot of processes and materials into one overall pool. It is often necessary to get more precise data on specific reactions or components.

3. Exponential Approach Toward an Asymptote

The above treatment assumes that all the added organic material will decay. This is often not so. Often when considering populations of microorganisms, there is a maximum that can be reached. If the decline of a substrate does not go to zero, then the decay curve approaches some other value, and the rate expression is based on the difference between the present value and the asymptote rather than the difference between the present value and zero (Riggs, 1963).

For example, loss of carbon from a substance in a soil in which the decay rate is 20%/year ($t\ 1/2 = 3.47$ yr) and a total of 80% will disappear is represented in figure 1, by the middle line. The upper line

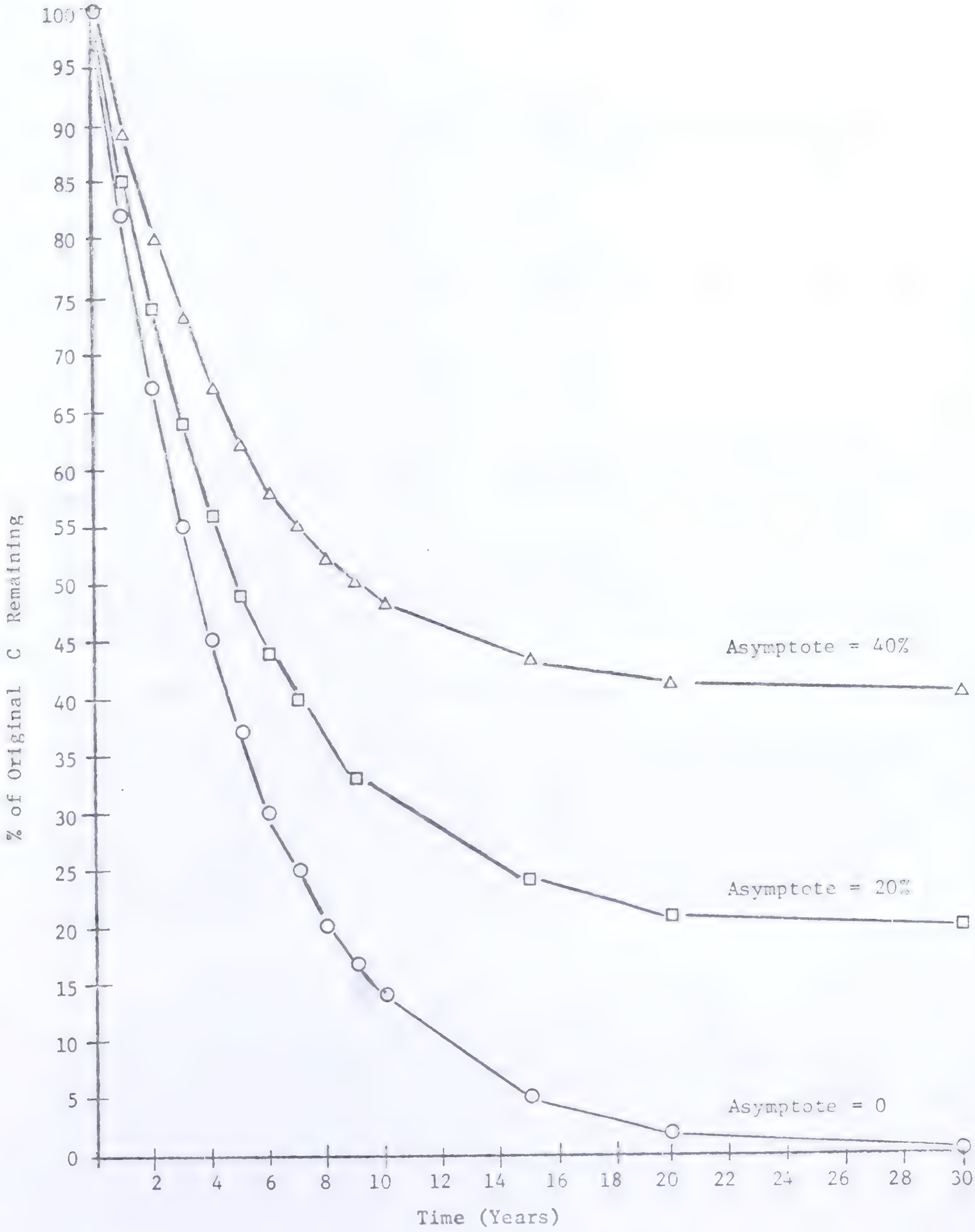


Figure 1. Effect of approach to an asymptote (adsorption, etc.) on loss of C from soil. All curves represent the same decay rate, i.e., 20% per year (k = 0.2 t½ = 3.47 years).

represents the same substrate in a different soil (e.g., higher clay content) that absorbs large quantities of substrate carbon and only 60% of the carbon is likely to be lost. The amount remaining after various time intervals is:

$$Yt = Yas + (Yo - Yas)\ e^{-kt}$$

Yt = amt. of remaining C at time t

Yas = amt. of remaining C at asymptote or amt. adsorbed etc.

Yo = original amt. of C

k = decay constant (0.2)

t = time in years

This equation can be applied to all cases of exponential decay whether an asymptote is approached or not. If the substrate can go to zero, simply plug 0 into the Yas term.

Decay of pesticides is likely to follow this type of system. Also most organic matter decay patterns are like this because of build-up of humus, adsorption, production of biomass etc. See the following references for more examples (Dahlman, 1968; Jenkinson, 1965 and 1971, McGill, 1971; Minderman, 1968).

4. Sums of Exponential and Curve Splitting

Most reactions occurring in soil are monitored by the simplest means possible (CO_2 evolution, loss of C, accumulation of NH_4 or NO_3, plant growth etc.). These integrate a large number of different processes. This results in a plot of the results on semilog paper producing a curve and not a straight line. This curve represents a number of individual processes leading to the same result. For example, decomposition of a number of substrates, all producing CO_2 as an end product but each at a different rate.

$$\text{Thus } Y_t = \pm Ae^{-k1t} \pm Be^{-k2t} \pm Ce^{-k3t}$$

The values of each constant (k) and its intercept can be obtained by graphical representation (Riggs, 1963). The first part of the curve is due to decrease in the most rapid process. This process rapidly reduces the substrate available to it and the curve becomes dominated by the next most rapid process which more slowly depletes its substrate supply. This can be extended to include several processes. The relative magnitude of the coefficients A and B will also determine how soon the first term becomes "negligibly small" but the rate constants are most important.

The curve can be split into its component parts after plotting on semilog paper. It is generally possible to determine the coefficient and rate constant of the slowest process by extending the last portion (generally straight line) back to time zero. The differences between the points of this line at the various times and the experimental points at

the same times forms the other exponential term. If these differences (plotted on semilog paper) produce a straight line, it represents the second term or process. If the line curves downward, then the straight line drawn originally to represent the slowest term should be lowered and have a smaller slope (Riggs, 1963). The last term's parameters are thus altered, the differences recalculated and plotted on semilog paper. A straight line plot would yield the parameters of the fastest process. If the difference plot curves upward, then more than one term is involved and the process is repeated until all the terms have been separated.

This technique is useful for application to both field and laboratory data for separating out processes in soil (Shields and Paul, 1973; Paul, 1970; Minderman, 1968; Bingeman, Varner and Martin, 1953; McGill *et al.* 1972). Figure 2 contains data from McGill (1971) in which labelled acetate was added to soil. These data can be seen to represent two markedly different exponential processes with different rates. The most rapid rate is of course the metabolism of pure acetate whereas microbial biomass and humus produced from it disappear much more slowly.

5. Mean Residence Time - Carbon Dating.

Carbon dating does not produce a specific age, but rather a mean residence time for the material being examined. This is analogous to the turnover time of the material as discussed earlier. It represents the average age of a range of materials in soil. Therefore the organic matter of a soil having a mean residence time of 1500 years would have a turnover rate of 1/1500 = 0.000667 or 0.0667%/year. Mean residence times (MRT) have been measured for some soils and soil fractions (Campbell, *et al.*, 1967). They range from 250 ±60 years to nearly 2000 years for the organic matter of the soil (Paul, 1969), and from 25 years for readily hydrolyzable humus to 1478 years for the non-hydrolyzable components in a soil having an MRT of 870 years for the total soil organic matter.

The problem with application of this type of data to management modelling is that it is of long term utility but provides very little if any indication of the yearly dynamics of organic material in soil. If these rates can be related to temperature, moisture, fertilizers, cropping and management practice they will be very valuable. I think they can and will be soon.

6. Rates of Enzyme Activities in Soil

Soil biological events are enzymatic and many can be represented by simple Michaelis kinetics. The rate of reaction is a function of amount of substrate and of the amount of enzyme (No. of organisms in soil plus stable adsorbed enzymes). Figure 3 indicates that at low substrate concentration, reaction rate follows first order kinetics as we have

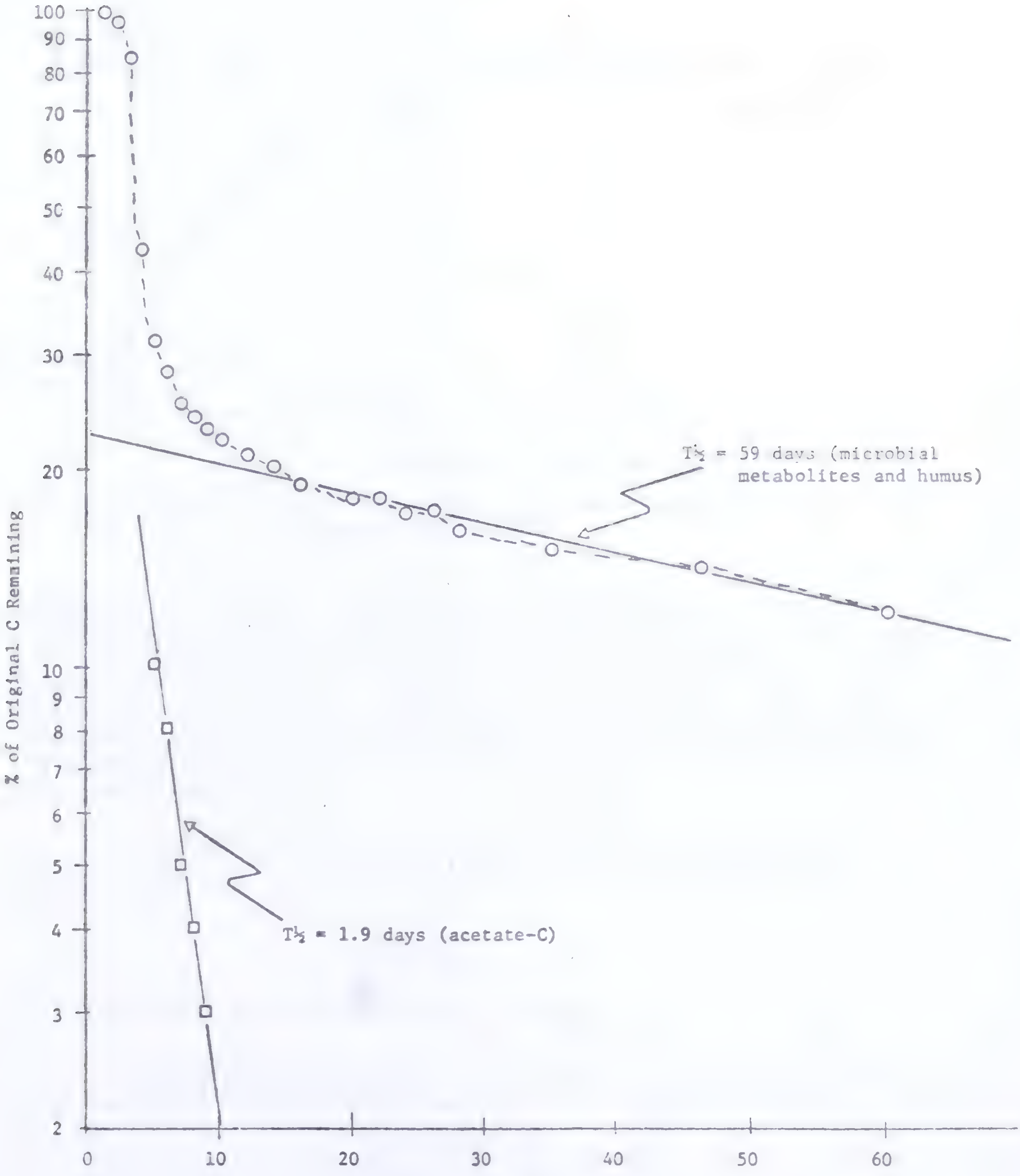


Figure 2. Use of curve splitting to separate decay rates of originally added acetate-C and of synthesized microbial metabolites and humus. From McGill (1971, p. 84). Temp = 15°C., @ Field Capacity Sceptre Clay (Brown Chernozem).

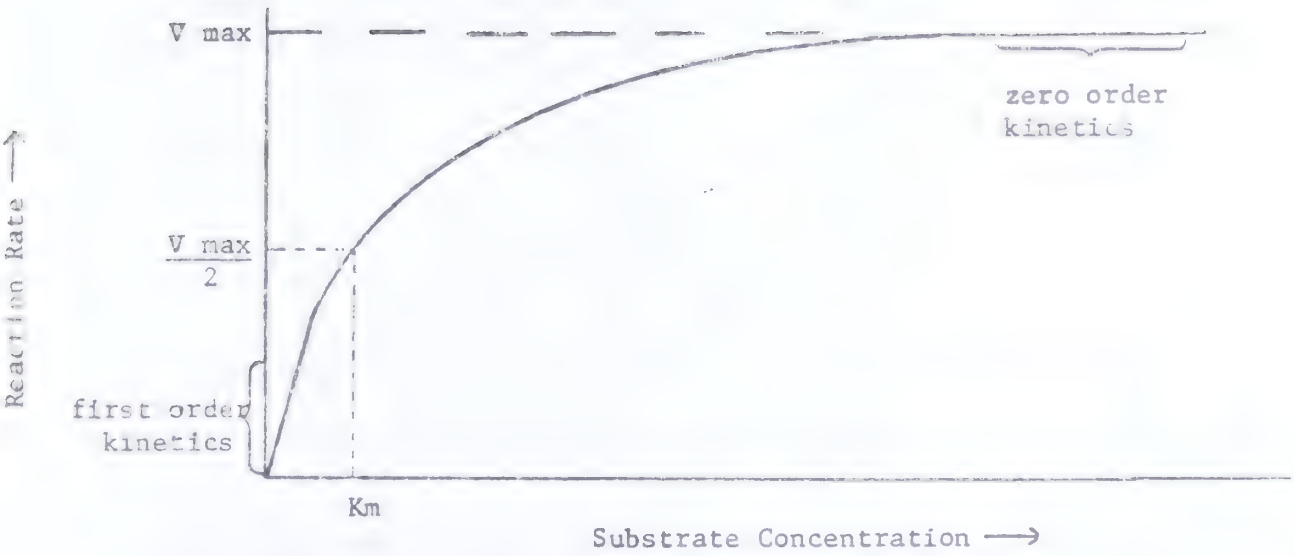


Figure 3. Effect of substrate concentration on an enzymatic reaction.

discussed up until now. However, first order kinetics do not hold at high substrate concentration and zero order kinetics occur. Response of crops to added nutrients follows a similar type of curve. At high doses of various materials (especially pesticides and certain organic pollutants) the concept of half life cannot be used. Also for nitrification, denitrification, sulfur oxidation and reduction, and probably both symbiotic and nonsymbiotic N fixation, Michaelis kinetics may be much more meaningful.

Reaction rate (v) is determined by the maximum possible velocity (Vmax), the Michaelis constant (Km) and the substrate concentration (S).

$$V = \frac{Vmax\ [S]}{Km + [S]}$$

Km is thus seen to be the [S] when $v = \frac{Vmax}{2}$

Two substrates may be involved (e.g., nitrification with NH_4^+ and NO_2^-) in which case (Bray and White, 1965 pp. 285-288)

$$v = \frac{V\ max\ [S_1]\cdot[S_2]}{(Km_1 + [S_1])\cdot(Km_2 + [S_2])}$$

The parameters Km and V max can be determined easily using Lineweaver Burk plots. The equation $v = \frac{V\ [S]}{Km + [S]}$ can be rewritten in a reciprocal form:

$$\frac{1}{v} = \frac{Km}{V\ max}\cdot\left(\frac{1}{[S]}\right) + \frac{1}{V\ max}$$

which is equivalent to the straight line equation y = ax + b.

Therefore if 1/v is plotted against 1/[S] the slope represents $\frac{Km}{V\ max}$ and the y intercept is $\frac{1}{V\ max}$ (Fig. 4).

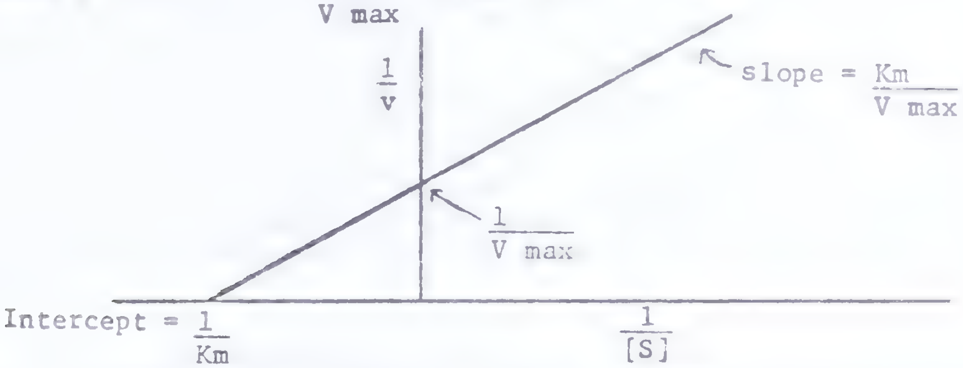
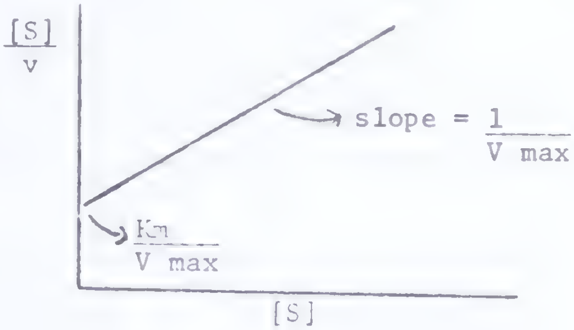


Figure 4. Lineweaver - Burke plot to obtain Km and V max.

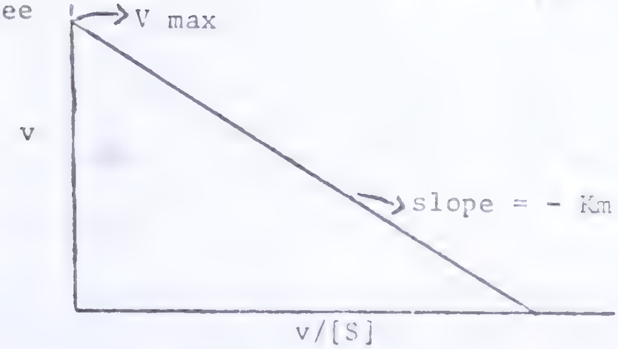
This eliminates the need to raise substrate concentrations up to very high levels. Excessive substrate levels are not desirable for several reasons and it is also difficult to know when you reach V max.

There are other ways of plotting the data to obtain V max and Km (Dowd and Riggs, 1965) besides the Lineweaver Burk plot.

a) Wolfe



b) Hofstee



The main restriction in using these plots is that the substrate concentration should be low relative to saturating conditions (i.e., remain in the first order region) and the change in substrate concentration should be small relative to the total amount of substrate. If the whole curve is to be plotted, rather than plotting reciprocals, the substrate concentration should be far in excess of what will be used in the time of the assay.

The constants obtained in this way are simple to use and provide a useful tool for management modelling. Maximum velocity and Km will both change from soil to soil. The main factors controlling V max is number of microorganisms. Km is modified by soil conditions affecting the organism - substrate interaction. A soil with a large adsorbant surface would have a higher Km for a pesticide than a sandy soil. As the affinity or availability of the substrate in the soil to the enzyme or organism decreases, Km increases. It would not take much more work to quantify the factors controlling V max and Km. They do appear to fluctuate within reasonably narrow limits for a given process.

These parameters have been used in soil modelling and have been calculated for a number of enzymes and soil processes (Tabatabai and Bremmer, 1971). For example Dr. M. J. Rowell (personal communication) using glucose $-{}^{14}C$ obtained Km values ranging from 0.28 to 1.7 μ moles glucose per g soil and V max values of 0.007 to 0.03 μ moles glucose respired per hour per g soil. Soils used included those from the N.W.T. and from oil spill experimental plots at Redwater. McGill and Reuss used this type of data in modelling soil N transformations in grassland soils. Many of the values used were only approximations inferred from the literature. Real data of the proper form are in limited supply. Some data in this regard are becoming available. Bowman and Focht (1974) for example present data on denitrification in two soils. Maximum denitrification rates varied from 1500 ug/g/day to 150 ug/g/day. The Km value for the latter was 170 ug NO_3-N/g soil. These rates were obtained at very high energy levels and the Km for glucose was 500 ug/g. Two "substrates" may be considered necessary as pointed out earlier. This is an example of such a situation.

Since most transformations in soil are dependent upon the amount of substrate and of enzyme (which is a function of numbers of microbes and adsorbed stable enzymes) every effort should be made to obtain the two fundamental constants (V max and Km) that define these. Factors affecting them must also be quantified. From the foregoing, it can be seen that gross estimates of turnover rate (half life, mean residence time etc.) while of considerable value will not provide the dynamic information necessary for intensive soil management.

7. Adsorption Isotherms

Kinetics of the Michaelis-Menten type are also applicable to adsorption of pesticides onto soil particles. They apply only to cases where the adsorption is primarily monomolecular but still provide a reasonable estimate of the amount of pesticide one can expect to be adsorbed or in solution in various soils. Increased availability of this data will make predictions of leaching losses, effectiveness, and breakdown more accurate. Its use in management modelling is obvious. The Langmuir adsorption equation is of the above form.

$$X = \frac{Xm \cdot b \cdot C}{1 + b \cdot C} \quad \text{(Weber and Gould, 1966)}$$

X = amount of solute adsorbed per g. of soil

Xm = maximum possible amount that can be adsorbed

b = constant related to energy of adsorption. The reciprocal, 1/b, is the concentration at which adsorption attains half its limiting Xm value.

c = solute concentration in solution at equilibrium. Two linear forms of the Langmuir equation (similar to the Lineweaver-Burke plots for Michaelis Menten kinetics) exist:

$$\frac{1}{X} = \frac{1}{Xm} + \frac{1}{bXm\ C}$$

$$\text{or} \quad \frac{C}{X} = \frac{1}{bXm} + \frac{C}{Xm}$$

The Frerendlich adsorption equation is an exponential function which implies that adsorption is a function mainly of amount of pesticide and that adsorption can be increased almost indefinitely. This equation ($X/m = k\ C^{\frac{1}{n}}$) has been found to fit the adsorption isotherms measured for many soils (Moyer *et al*., 1972; Talbert and Fletchall, 1965; Harris and Warren, 1964; Yuen and Hilton, 1962; Bailey *et al*., 1968).

X = amount of pesticide adsorbed

m = wt. of soil or adsorbent

k = adsorption constant (amount adsorbed per unit of pesticide present - ug/g soil adsorbed in equilibrium with a 1 ug/ml solution)

n = hard to define. It is the slope of the line represented by $\ln \frac{X}{m} = \ln k + n \ln C$. It reflects the degree of nonlinearity of adsorption. If $n=1$, then adsorption depends only on amount of pesticide. For many soils and pesticides, $n \neq 1$ and may vary between 1 and 0.6 (Osgerby, 1970), but usually does not fall below 0.85. Thus soils can often be readily compared by comparing k values; higher k values are associated with greater adsorption. Likewise a range of pesticides can be compared for a given soil. For example Moyer *et al*. (1972) found that adsorption was increased 55 to 1500 fold for various herbicides by charcoal addition to a sandy loam soil containing 2.5% organic matter. It is interesting to note that although the adsorption increased by 55 to 1500 times, decomposition rate was not reduced by more than a factor of 3 - 5.

E. Types of Models Presently in Use.

1) Yield prediction equations:

These models contain little explicit biological information but a reasonable amount of implicit information. These models are useful for general predictions and are a very valuable tool at the present level of soil management. Many of these equations are being used by different people, developed in a slightly different framework and with different soils, climatic conditions and Agriculture practices. The equation by Soper et al. (1971) is only one such example:

$$y = 2.03 + 2.57\,X - 0.0163X^2$$

y = N uptake by barley in Manitoba

X = N in soil (0-60 cm) at seeding time.

Three features should be pointed out here:

1) These equations are nearly all regression equations. This means that they are used because they seem to fit certain experimental data, why they work is often rather unclear.

2) These are general equations which provide general guidelines. Problems arise though, when managers expect specific answers for their specific soil. The equations in use now work for the nonexistent "average" soil.

3) At the present they are probably the most practical models to use. To improve on them we need more explicit soil biological information in them. More intensive management practices are necessary to utilize sophisticated models. The more precise we want our management models to be, the more precise our input data and ideas will have to be. At present much of our data is very imprecise. There is a need for more information for each soil in terms of its dynamic characteristics. Possibly some of this could be obtained through soil survey programs.

2) Nitrogen and Phosphorus Turnover Models

The models in this category with which I am familiar (Stewart and Cole, 1974; McGill and Reuss, 1974; Dutt, Shaffer and Moore, 1972; Beek and Frissel, 1973) all use a large amount of explicit soil data in the area of microbiology and biochemistry. They have been developed for predicting P turnover in soil (Stewart and Cole - personal communication) N turnover through grassland systems (McGill and Reuss) and N entry into groundwater primarily (Dutt et al.). As input they require a large amount of state variable data for each soil as opposed to the earlier group which uses only NO_3 - N etc. at seeding time. This data includes, texture, pH, CEC, moisture retention characteristics, numbers of microorganisms, plant root mass, type of grassland (growth characteristics and phenology) amount of organic matter and a general idea of type of organic matter plus a large pool of information on the dynamics of decomposition, leaching, denitrification

mineralization, nitrification and microbial growth and death rates.

Fig. 5 represents the flow of N through a grassland system. The flow rate is controlled by soil temperature and moisture and the amount of N in various compartments is interrelated to processes operating in other parts of the system. This model developed by McGill and Reuss for grassland systems can be used to predict the effect of N fertilizer, removing the forage etc. on productivity of the soil-plant system.

Output from this model (fig. 6) helps illustrate changes occurring in the N content of above ground plant material, and of plant roots, as the season progresses. The N concentration of the roots drops as top growth starts to demand more N. Nitrogen concentration in the above ground parts increases during the early summer when total above-ground biomass is low. Rapid top growth soon depletes the N supply in the roots and dilutes the N concentration in the plant tops. As summer progresses senescence and death cause loss of leaves and loss of N from plant tops. Growth slows and N concentration in the roots starts to increase, with root uptake taking advantage of N mineralized during the growing season. This provides N storage for starting the next season's growth off quickly before N mineralization starts. The use of this type of model helps managers plan their programs to make maximum use of the natural biological processes occurring in soil-plant systems. Fig. 6 also helps explain yield increases in grassland in years following addition of N late in the previous season.

Detailed information on the dynamics of soil nutrients can also be obtained from the use of models (fig. 7). The dynamics of labile soil organic N are very difficult to follow experimentally. The accumulation of labile N as old litter from the previous year starts to break down (mid April) shows up clearly. Some N mileralization is also evident at this time of year. Decomposition of this labile organic N continues through the summer but production doesn't. The loss of labile N can be seen to be compensated by an increase in nitrate N. In the fall, death of old plant parts and their partial decomposition cause a second wave in production of new labile N. This can be expected to be carried over into the succeeding year, decompose and release mineral N. Managers will want to keep the pool of labile N large since it is the most readily available form of organic N from which mineral N is derived. It turns over rapidly, hence if the pool is large, large amounts of mineral N are released annually.

Although information derived from this type of model is very useful and practical, it suffers some serious shortcomings. The model does not include denitrification, leaching, or nitrogen fixation. These processes must eventually be incorporated. More serious is the problem that it does not encompass more than one nutrient and ignores effects of plant growth and microbial activities on other soil properties.

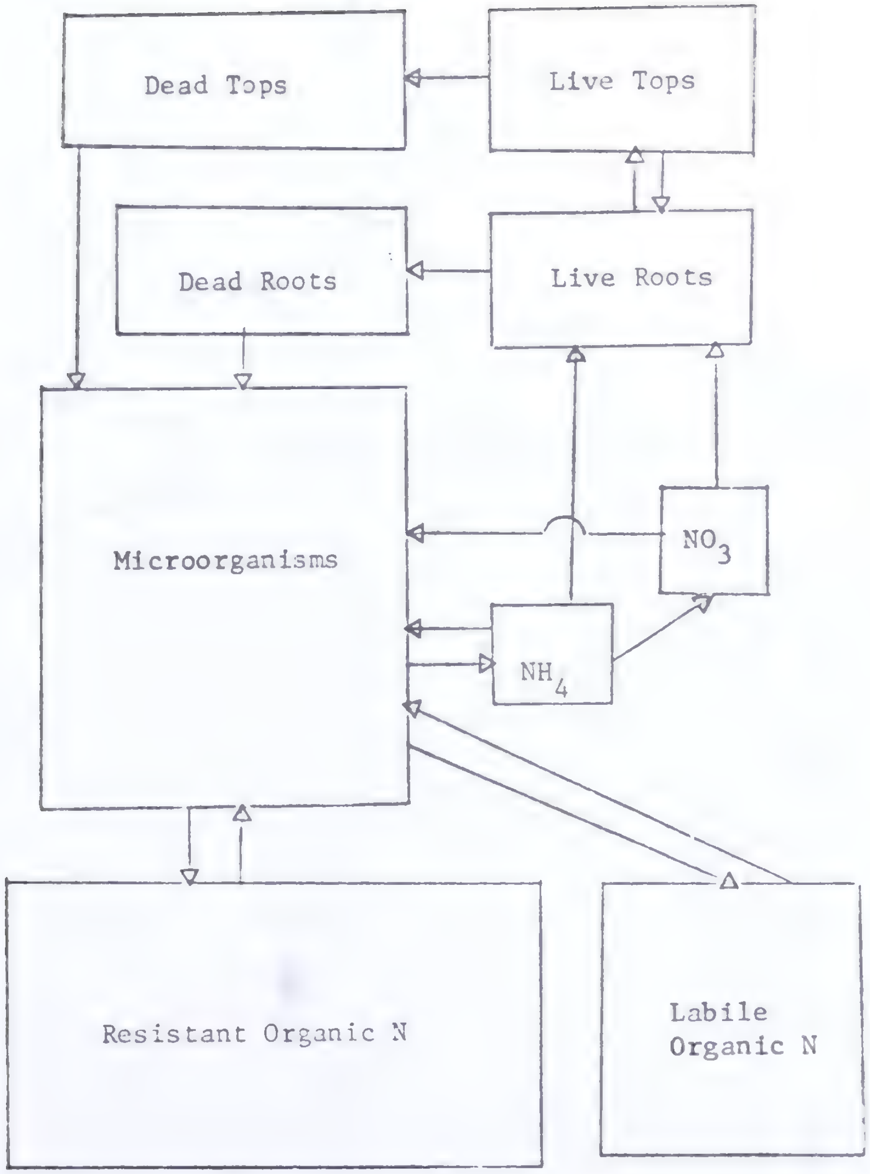


Figure 5. N flow through a grassland soil--general schematic representation.

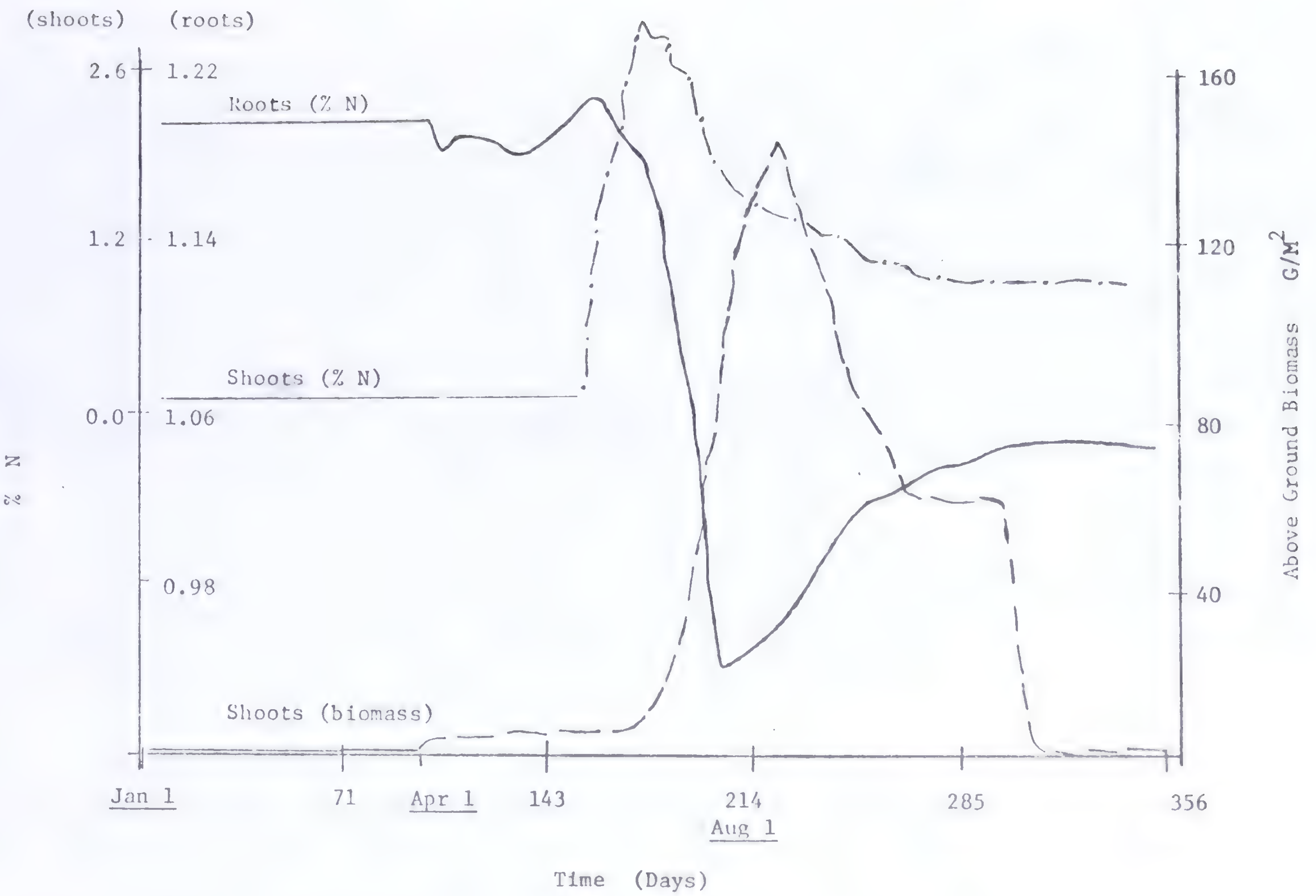
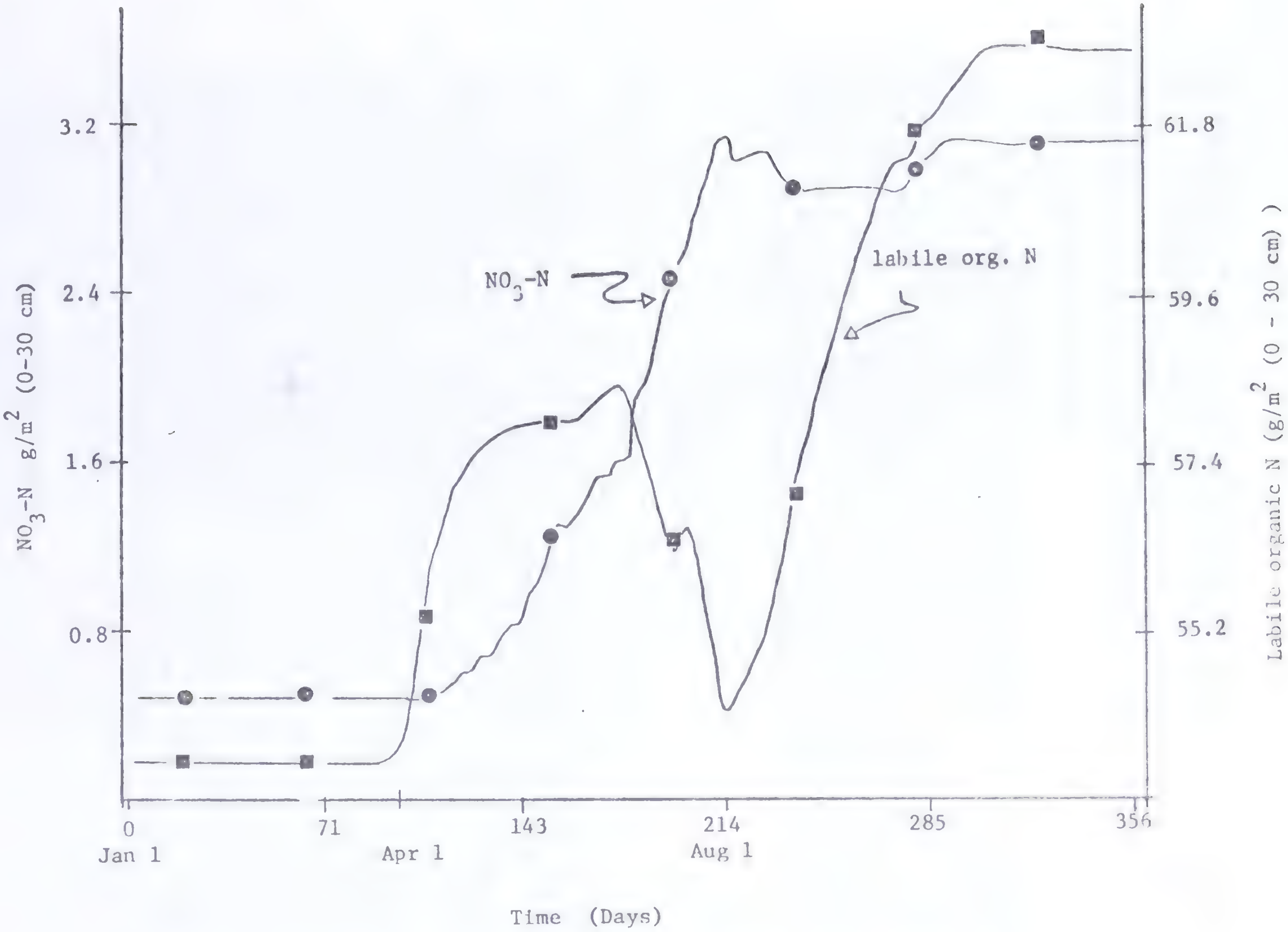


Figure 6. Model simulation of %N in roots and shoots of above ground biomass in a native grassland on a Brown Clay (Sceptre) soil in Saskatchewan using soil moisture and temperature data from 1969.



<u>Figure 7</u>. Simulated NO_3 and labile organic N levels in a brown clay grassland soil using soil temperature and moisture data for 1969.

Maximum use can be derived from this model and others like it if they are integrated into or become sub routines of larger but more general models. This type of model would have tremendous utility in Range Management and in Forestry. Its application in Agriculture to small field conditions is still some distance into the future.

3) Single Process Models

Nitrification has been modelled as a single isolated process using ideal or model systems (McLaren, 1969, 1971; McLaren and Ardakani, 1972). These models provide accurate dynamic tools for researchers in understanding and working with specific processes but are of little value for direct practical application at present. Their main utility is as submodels of larger models. Another problem apart from their narrow scope is that many models of this kind are developed for very artificial systems. Artificially simplified and controlled systems make research easier but extrapolation of the results to the real world is difficult and should be undertaken with extreme caution.

CONCLUSIONS

Modelling will be useful in soil management only if we provide the necessary kinetic data. Much remains to be done in this regard. We have already started in terms of yield prediction equations but must proceed beyond this for both long and short term accuracy. Modelling entails describing how soil works and what controls the rates. This is only one part of the whole-system or systems analysis approach necessary to soil management. The collection of proper kinetic data and modelling must proceed concurrently and must involve people from many areas of soil science working together. The value of models lies in the framework they provide within which information from diverse soil disciplines can be integrated in a useful and practical way. Soil biologists and biochemists will have to shift some of their efforts from the qualitative work that has dominated the past to more quantitative aspects if we are to provide the kinetic data needed. Rigorous delineation of the quantitative aspects of factors controlling soil biological processes is needed. More effort is needed to quantify the magnitude of organism interactions in soil and of the effect of soil organisms on soil properties.

REFERENCES CITED

Bailey, G.W., J.L. White and T. Rothberg. 1968. Adsorption of organic herbicides by Montmorillonite. Role of pH and chemical character of adsorbate. Soil Sci. Soc. Am. Proc., 32:222-234.

Beek, J. and M.J. Frissel. 1973. Simulation of nitrogen behaviour in soils. Centre for Agricultural Publishing and Documentation, Wageningen. pp 67.

Bingeman, C.W., J.E. Varner and W.P. Martin. 1953. The effect of the addition of organic materials on the decomposition of an organic soil. Soil Sci. Soc. Am. Proc., 17:34-38.

Bowman, R.A. and D.D. Focht. 1974. The influence of glucose and nitrate concentrations upon denitrification rates in sandy soils. Soil Biol. Biochem, 6:297-301.

Bray, H.G. and K. White. 1966. Kinetics and thermodynamics in biochemistry. Acad. Press., New York.

Campbell, C.A., E.H. Paul, D.A. Rennie, and K.J. McCallum. 1967. Applicability of the carbon-dating method of analysis to soil humus studies. Soil Sci. 104:217-224.

Dahlman, R.C. 1968. Root production and turnover of carbon in the root-soil matrix of a grassland ecosystem. In Symposium on Methods of Productivity Studies in Root Systems and Rhizosphere Organisms. U.S.S.R. Aug. 28 - Sept. 12, 1968.

Dowd, J.E. and D.S. Riggs. 1965. A comparison of estimates of Michaelis-Menten kinetic constants from various linear transformations. J. Biological Chem., 240:863-869.

Dutt, G.R., M.J. Shaffer and W.J. Moore. 1972. Computer simulation model of dynamic Bio-physicochemical processes in soil. Tech. Bull. 196 Agric. Exp. Stn. U. of Arizona, Tueson.

Harris, C.I. and G.F. Warren. 1964. Adsorption and desorption of herbicides by soil. Weeds, 12:120-126.

Jenkinson, D.S. 1965. Studies on the decomposition of plant material in soil. I. Losses of carbon from C14 labelled ryegrass incubated with soil in the field. J. Soil Sci., 16:104-115.

McGill, W.B. 1971. Turnover of microbial metabolites during nitrogen mineralization and immobilization in soil. Ph.D. thesis. U. of Saskatchewan, Dept. Soil Sci.

McGill, W.B., E.A. Paul, J.A. Shields and W.E. Lowe. 1972. Turnover of microbial populations and their metabolites in soil. In: Modern Methods in the study of microbial ecology. T. Rosswall ed. pp. 293-302.

McGill, W.B. and J. Reuss. 1974. Nitrogen model for grassland systems. Joint U.S.-Canada IBP project. Unpublished.

McLaren, A.D. 1969. Nitrification in Soil: Systems approaching a steady state. Soil Sci. Soc. Am. Proc., 33:551-556.

McLaren, A.D. 1971. Kinetics of nitrification in soil: Growth of the nitrifiers. Soil Sci. Soc. Am. Proc., 35:91-95.

McLaren, A.D. and M.S. Ardakani. 1972. Competition between species during nitrification in soil. Soil Sci. Soc. Am. Proc., 36:602-606.

Minderman, G. 1968. Addition, decomposition and accumulation of organic matter in forests. J. Ecol., 56:355-362.

Moyer, J.R., R.J. Hance and C.E. McKone. 1972. The effect of adsorbents on the rate of degradation of herbicides incubated with soil. Soil Biol. Biochem., 4:307-311.

Osgerby, J.M. 1970. Sorption of un-ionised pesticides by soils. In: Sorption and transport processes in soils. J.G. Gregory ed. Soc. Chem. Ind. Monograph No. 37 pp:63-78.

Paul, E.A. 1969. Characterization and turnover rate of soil humic constituents. In: Pedology and Quaternary Research. S. Pavluk ed. pp:63-76.

Paul, E.A. 1970. Plant Components and Soil Organic Matter. Recent Adv. in Phytochem., 3:59-104.

Riggs, D.S. 1963. The mathematical approach to physiological problems. William & Wilkins Co. Baltimore. pp. 429.

Shields, J.A., and E.A. Paul. 1973. Decomposition of 14C - labelled plant material under field conditions. Can. J. Soil Sci., 53:297-306.

Soper, R.J., G.J. Racz and P.I. Fehr. 1971. Nitrate nitrogen in the soil as a means of predicting the fertilizer requirements of barley. Can. J. Soil Sci., 51:45-50.

Stewart, J.W.B. and V. Cole. 1974. Phosphorus model for grassland soils. Joint U.S.-Canada IBP project. Unpublished.

Tabatabai, M.A. and J.M. Bremner. 1971. Michaelis constants of soil enzymes. Soil Biol. Biochem., 3:317-323.

Talbert, R.E. and O.H. Fletchall. 1965. The adsorption of some s-triazines in soils. Weeds, 13:46-52.

Watt, K.E.F. 1966. The nature of systems analysis. In: Systems Analysis in Ecology. p1-14. K.E.F. Watt ed. Academic Press, New York.

Weber, W.J. jr. and J.P. Gould. 1966. Sorption of organic pesticides from aqueous solution. In: Organic pesticides in the environment. R.F. Gould ed. Adv. Chem. Series 60. pp 280-305.

Yuen, O.H. and H.W. Hilton. 1962. The adsorption of monuron and diuron by Hawaiian sugarcane soils. J. Agr. Food Chem., 10:386-392.

A SOIL MOISTURE AND TEMPERATURE PREDICTION MODEL AS RELATED TO SOIL MANAGEMENT

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1. Introduction

Conservation of soil moisture is perhaps the most important aspect of proper soil management. In water deficient areas, it is estimated that about sixty percent of the precipitation is evaporated back into the atmosphere (Hanks *et al*. 1967). Because of the great importance of evaporation, much research has been directed towards developing a greater understanding of evaporation and thus find means of reducing evaporation losses.

The process of evaporation at the soil surface reflects the energy and mass transport interactions that occur between the soil and atmosphere which form a thermodynamic continuum. In order to fully examine the extent of the interactions, consideration must be given to the transfer processes in each region. The mechanisms and magnitudes of heat and mass transfer differ vastly in each domain. The surface of the earth then becomes the interface between the two domains in which energy and mass transfer occur. Both domains serve, at one time or another, as sources and sinks for heat and mass. Since both transfer processes are coupled in each region, the flux of heat and mass away from the interface, into the atmosphere or earth, influences the transfer of heat and mass in both domains.

The development of models to describe moisture and temperature fields in the soil in response to evaporation from a bare soil has been restricted to steady state systems. For example, implied in a steady-state system is a steady moisture field above a water table that remains at constant depth and is constantly replenished by lateral drainage. Although such a situation is not common, it is by no means universal. Similarly, a steady-state model of the temperature in the soil assumes at a certain depth the temperature remains constant.

Philip (1957) recognized the need for extending the steady-state models describing heat and moisture fields to more difficult and complex problems of unsteady conditions produced by nature in the diurnal cycle.

A model that may be employed for the prediction of soil-water and temperature fields under drying conditions will be presented. The mathematical model provides an analytical statement of energy and mass transport for the drying of a homogeneous soil under evaporative conditions. Included is the identification and modelling of three stages of drying with mass and energy equations and, more importantly, the boundary conditions. By means of dimensional analysis the relative importance of the modes of mass and energy transport during the drying process will be delineated.

Other possible applications and uses of a soil-water and temperature prediction model will also be examined.

2. Model Description

A one-dimensional, semi-infinite column of soil of a known initial moisture content and temperature profile is assumed to be exposed to measurable atmospheric conditions. The soil-water content and temperature field, as functions of the space coordinate z', and time t are denoted by $\theta(z', t)$ and $T(z', t)$ respectively where $o \leq z' \leq \infty$ and $o \leq t < \infty$.

Two distinct phases of the evaporation process have been observed to occur (Keen, 1914; Fisher, 1923; Penman, 1941; Lemon, 1956), a constant-rate phase and falling-rate phase. During the constant-rate phase the evaporation demand is fulfilled in the first instance by liquid transfer to the surface and then subsequently by both liquid and vapor transfer to the surface. Consequently, the evaporation rate and moisture and temperature fields are

governed by prevailing meteorological conditions. However, during the falling-rate phase, the evaporation process is rate-limited by vapor diffusion within the soil.

For the solution of the problem, it is essential to partition the energy that is available for vaporization. The basic assumption is made that, at every instant, equilibrium conditions exist in the soil between liquid and vapor. This assumption, in the low soil-water content range, is similar to assuming that vapor diffusion and thermal energy conduction in the soil limit evaporation. This assumption may be analytically described by the relationship

$$\theta_v = \theta_v\,(\theta_\ell\ , T). \qquad \ldots.[2.1]$$

In particular

$$\theta_v = (S-\theta_\ell)\rho_v/\rho_\ell\ , \qquad \ldots.[2.1a]$$

and thus $\theta_v = (S - \theta_\ell)\ \rho_o h/\rho_\ell$ ....[2.1b]

where S = porosity (cm^3/cm^3),

ρ_v = density of water vapor in air (gm/cm^3),

ρ_o = density of saturated water vapor (gm/cm^3),

ρ_ℓ = density of liquid water (gm/cm^3),

h = relative humidity,

and θ_v and θ_ℓ are as previously defined.

The relative humidity, h, is a function of both temperature and θ_ℓ, the liquid soil-water content. This relationship may be determined experimentally or calculated from a thermodynamic relationship (Philip and de Vries, 1957). The relationship between θ_ℓ and h at constant temperature is usually referred to as an adsorption isotherm.

A. Constant-rate Phase Model

(a) Evaporative demand of the atmosphere is fulfilled by liquid transfer to the soil surface.

(i) Initial Conditions:

The initial conditions for the temperature and water content fields may be described by

$T(z',0) = T_1(z')$, the initial temperature profile, ...[2.2a]

$\theta(z',0) = \theta_1(z')$, the initial soil water content profile ....[2.2b]

$\theta(0,0) > \theta_m$ ....[2.2c]

where $T(z',0)$ is the soil temperature as a function of the space coordinate z' at time, $t = 0$. Similarly $\theta_\ell(z',0)$ is the soil-water content as a function of the space coordinate z' at time, $t = 0$. θ_m is defined as the moisture content at the soil surface above which the total transfer takes place in the liquid phase. Rose (1963a,b) determined vapor movement was negligible in soils at soil-water contents in excess of 0.15 (gm/cm^3).

(ii) Boundary Conditions:

The mass flux boundary condition is given by

$$E_s = D \frac{\partial \theta_\ell(0,t)}{\partial z'} + D_{T\ell} \frac{\partial T(0,t)}{\partial z'} - K(0,t) \qquad ....[2.3]$$

for $0 < t < t_1$

where E_s = rate of evaporation (cm/sec) is > 0,

t_1 = the end of the time period in which all transfer to the surface is in the liquid phase,

and the remaining terms are as previously defined.

Equation (2.3) is a statement of the equality of mass flux across the interface between the soil and the atmosphere. The left hand side of the equation is considered to be constant for the model evaluation since q_ℓ and T_a are fixed for any instant of time by the prevailing atmospheric conditions.

The energy flux boundary condition is given by

$$\lambda\frac{\partial T}{\partial z'}(0,t) - H + C_\ell\rho_\ell q_\ell)\ [\ T(0,t)\ ] = \rho_\ell q_\ell L - HT_a - R_n \qquad \ldots.[2.4]$$

for $0 < t < t_1$

where H = heat transfer coefficient between the soil surface and a reference height above the soil surface ($cal/cm^2 sec°C$),

R_n = net radiation ($cal/cm^2 sec$),

T_a = air temperature at screen height °C,

L = latent heat of vaporization (cal/gm).

Equation (2.4) is a statement of the equality of the energy flux across the interface between the soil and the atmosphere.

(iii) Moisture and Temperature Field Equation:

$$C_1\frac{\partial T}{\partial t} = \frac{\partial}{\partial z'}\left[\lambda\frac{\partial T}{\partial z'}\right] - C_\ell\rho_\ell q_\ell\frac{\partial T}{\partial z'} \quad \text{for } 0 \leq z' < \infty,\ 0 < t < t_1 \qquad \ldots.[2.5]$$

where $C_1 = C$, the heat capacity per unit volume of soil ($cal/cm^3 °C$) and the equation for moisture by:

$$\frac{\partial\theta_\ell}{\partial_t} = \frac{\partial}{\partial z}\left[D_{\theta\ell}\frac{\partial\theta_\ell}{\partial z}(z',t)\right] + \frac{\partial}{\partial z}\left[D_{T\ell}\frac{\partial T}{\partial z}(z',t)\right] - \frac{\partial K}{\partial z}(z',t) \qquad \ldots.[2.6]$$

for $0 \leq z' \leq \infty$, $0 < t < t_1$

(b) Evaporative demand of the atmosphere is fulfilled by both liquid and vapor transfer to the soil surface.

(i) Initial Conditions

The initial conditions at the beginning of the second stage of drying, at time $t = t_1$, for the temperature and soil-water content fields are given by:

$T(z', t_1)$ = temperature profile at the end of the first stage of drying, ...[2.7a]

$\Theta(z', t_1)$ = water content profile at the end of the first stage of drying, ...[2.7b]

$$\theta_n < \theta(0,t) \leq \theta_m \qquad \text{....[2.7c]}$$

where θ_n is the moisture content below which the transfer takes place totally in the vapor phase. Philip and de Vries (1957) and Jackson (1964a,b,c, 1965) suggest that liquid continuity fails at relative vapor pressures less than 0.60.

(ii) Boundary Conditions

The mass flux boundary condition is specified by:

$$E_s = D_\theta \frac{\partial \theta_\ell (0,t)}{\partial z'} + D_T \frac{\partial T}{\partial z'}(0,t) - K(0,t) \qquad \text{....[2.8]}$$

for $t_1 < t < t_2$

where t_2 is the end of the time period in which the evaporative demand of the atmosphere is met by the transfer to the surface in both the liquid and vapor phase. For $t < t_2$, equation (2.8) is a statement of the equality of the evaporation from the soil surface and the liquid and vapor flux to the soil surface.

The energy flux boundary condition is described by:

$$\lambda\frac{\partial T}{\partial z}(0,t) - T(0,t)\ [\ H + C_{\ell}q_{\ell}\rho_{\ell} + C_{p}q_{v}\rho_{v}\ ]$$

$$= q_{\ell}\rho_{\ell}L - HT_{a} - R_{n},\ \text{for } t_1 < t < t_2 \qquad \text{....[2.9]}$$

Equation (2.9) is a statement of the equality of the energy flux across the interface between the soil and the atmosphere.

(iii) Moisture and Temperature Field Equations:

The temperature and moisture field equations for this portion of the constant-rate stage of drying are given respectively by:

$$C_1\ \frac{\partial T(z',t)}{\partial t} = \frac{\partial}{\partial z'}\left[\lambda\frac{\partial T(z',t)}{\partial z'}\right] - C_{\ell}q_{\ell}\rho_{\ell}\ \frac{\partial T}{\partial z}(z',t)$$

$$- C_{p}q_{v}\rho_{\ell}\ \frac{\partial T}{\partial z'}(z',t) - L\rho_{\ell}E_{z'}(z',t) \qquad \text{....[2.10]}$$

for $0 < z < \infty$,

$t_1 < z < t_2$,

and

$$\frac{\partial \theta(z',t)}{\partial t} = \frac{\partial}{\partial z'}\left[D_{\theta}\ \frac{\partial \theta(z',t)}{\partial z'}\right] + \frac{\partial}{\partial z}\left[D_{T}\ \frac{\partial T(z',t)}{\partial z'}\right] - \frac{\partial K}{\partial z'} \qquad \text{....[2.11]}$$

for $0 < z < \infty$,

$t_1 < t < t_2$.

$E_{z'}(\sec^{-1})$ is defined as the rate of evaporation within the soil profile. An expression for $E_{z'}(z',t)$ is derived as follows, according to de Vries (1958),

$$\frac{\partial \theta_{\ell}}{\partial t} = \frac{\partial}{\partial z'}\left[D_{\theta\ell}\ \frac{\partial \theta_{\ell}}{\partial a'}\right] + \frac{\partial}{\partial z'}\left[D_{T\ell}\ \frac{\partial T}{\partial z'}\right] - \frac{\partial K}{\partial z'} - E_{z'}(z',t), \qquad \text{....[2.11a]}$$

$$\frac{\partial\theta_v}{\partial t} = \frac{\partial}{\partial z'}\left[D_{\theta v}\frac{\partial\theta_\ell}{\partial z'}\right] + \frac{\partial}{\partial z'}\left[D_{Tv}\frac{\partial T}{\partial z'}\right] + E_{z'}\,(z',t) \qquad ....[2.11b]$$

and

$$\frac{\partial\theta_v}{\partial t} = \left[\frac{D_{\theta v}}{\propto\nu D_{atm}} - \frac{\rho_v}{\rho_\ell}\right]\frac{\partial\theta_\ell}{\partial t} + \frac{(S-\theta_\ell)}{\rho_\ell}\,h\beta\,\frac{\partial T}{\partial t} \;, \qquad ....[2.11c]$$

where θ_v = volumetric vapor content, cm^3 or precipitable water/cm^3,

D_{atm} = molecular diffusion coefficient of water vapor in air (cm^2/sec),

$\beta = \frac{d\rho_o}{dT}$ (gm/cm^3 °C),

and the remaining terms are as previously defined. Equation (2.11c) is based on the relationship between θ_v and θ_ℓ given by equation (2.1b). Solving for $E_{z'}$ (z',t) results in

$$E_{z'}\,(z',t) = \frac{V_{11}}{V_{11}+1}\,\frac{\partial}{\partial z'}\left[D_{\theta\ell}\frac{\partial\theta}{\partial z'}\right] + \frac{V_{11}}{V_{11}+1}\,\frac{\partial}{\partial z}\left[D_{T\ell}\frac{\partial T}{\partial z}\right] + \frac{R_{11}}{V_{11}+1}\,\frac{\partial T}{\partial t} - \frac{1}{V_{11}+1}\,\frac{\partial}{\partial z'}\left[D_{\theta v}\frac{\partial\theta}{\partial z}\right] - \frac{1}{V_{11}+1}\,\frac{\partial}{\partial z}\left[D_{Tv}\frac{\partial T}{\partial z}\right] \qquad ....[2.11d]$$

$$\text{where } V_{11} = \frac{D_{\theta v}}{\propto\nu D_{atm}} - \frac{\rho_v}{\rho_\ell} \;, \qquad ....[2.11e]$$

$$\text{and } R_{11} = \frac{(S-\theta_\ell)h\beta}{\rho_\ell} \;. \qquad ....[2.11f]$$

B. Falling-rate Phase Model

(i) Initial Conditions: the initial conditions at time $t = t_2$, for the temperature and water content fields are given by:

$T(z', t_2)$ = temperature profile at the end of the second stage of drying, ...[2.12a]

$\theta(z',t_2)$ = water content profile at the end of the second stage of drying, ...[2.12b]

$\theta(0,t_2) = \theta_n$ ....[2.12c]

(ii) Boundary Conditions:

A mass transfer formula, developed by Chamberlain (1968), from wind tunnel experiments is employed as a means of describing the mass transport away from the soil surface into the atmosphere. Chamberlain (1968) has shown by experimentation that the formula adequately describes the rate of transport of mass and momentum away from a saturated soil surface under steady-state conditions. The equation, written for neutral atmospheric conditions is given by

$$E_s = u_* \rho_a \frac{(h_o - h_a)}{B^{-1}} \qquad \text{....[2.13]}$$

where u_* = friction velocity (sm/sec),

ρ_a = density of air (gm/cm^3)

h_o = specific humidity at the soil surface,

and h_a = specific humidity at screen height,

$$B^{-1} = \gamma \left[\frac{30\ U\ Z_o}{\nu}\right]^m \left[\frac{\nu}{D_{atm}}\right]^n \qquad \text{....[2.14]}$$

$\gamma = 0.5$ = constant,

ν = kinematic viscosity (cm^2/sec) = 0.1529,

U = wind velocity (cm/sec),

D_{atm} = diffusivity of vapor (cm^2/sec),

$m = 0.45$,

$n = 0.8$,

Z_o = roughness height (cm).

Equation (2.14) is a statement relating the evaporation from the soil surface to the water content at the soil surface. The water content of the soil surface governs the rate of evaporation. The process becomes rate-limited since the rate of evaporation is dependent on the transport characteristics of the soil.

The mass flow boundary condition may then be written as:

$$E_s = D_\theta \frac{\partial \theta}{\partial z'}(0,t) + D_T \frac{\partial T}{\partial z'}(0,t) - K(0,t) \qquad \ldots.[2.15]$$

for $t > t_2$

The energy flux boundary condition may be described by

$$\lambda \frac{\partial T}{\partial z'}(0,t) - T(H - C_p \rho_\ell q_v) = -(HT_a + R_n) \qquad \ldots.[2.16]$$

for $t > t_2$

(iii) Moisture and Temperature Field Equation:

The temperature and moisture field equations for the falling rate stage of drying are respectively given by:

$$C_1 \frac{\partial T}{\partial t} = \frac{\partial}{\partial z'} \left[\lambda \frac{\partial T}{\partial z'}\right] - C_p q_v \frac{\partial T}{\partial z'} - \rho L E_{z'}(z',t) \qquad \ldots.[2.17]$$

for $0 < z' < \infty$

and $t > t_2$

and

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z'} \left[D_\theta \frac{\partial \theta}{\partial z'}\right] + \frac{\partial}{\partial z'} \left[D_T \frac{\partial T}{\partial z'}\right] - \frac{\partial K}{\partial z'} \qquad \ldots.[2.18]$$

for $0 < z' < \infty$

and $t > t_2$

During each stage of drying the transport coefficients (D_θ and D_T) in the transport equations are defined differently, depending whether the mass transfer is in the liquid, liquid plus vapor or vapor form.

3. Model Predictions of Water Content and Temperature Profiles

Utilizing a Guelph loam soil for which the soil physical characteristics have been determined, predicted soil-water and temperature profiles at the end of each stage of drying for various evaporation rates are given by Fig. 3.1 and Fig. 3.2. Examination of these profiles indicates that the profiles at the end of each stage of drying were not appreciably influenced by the evaporation rates. The times required for the ends of the first, second and third stages of drying respectively, for each of the evaporation rates employed, are proportional to the evaporative rates imposed.

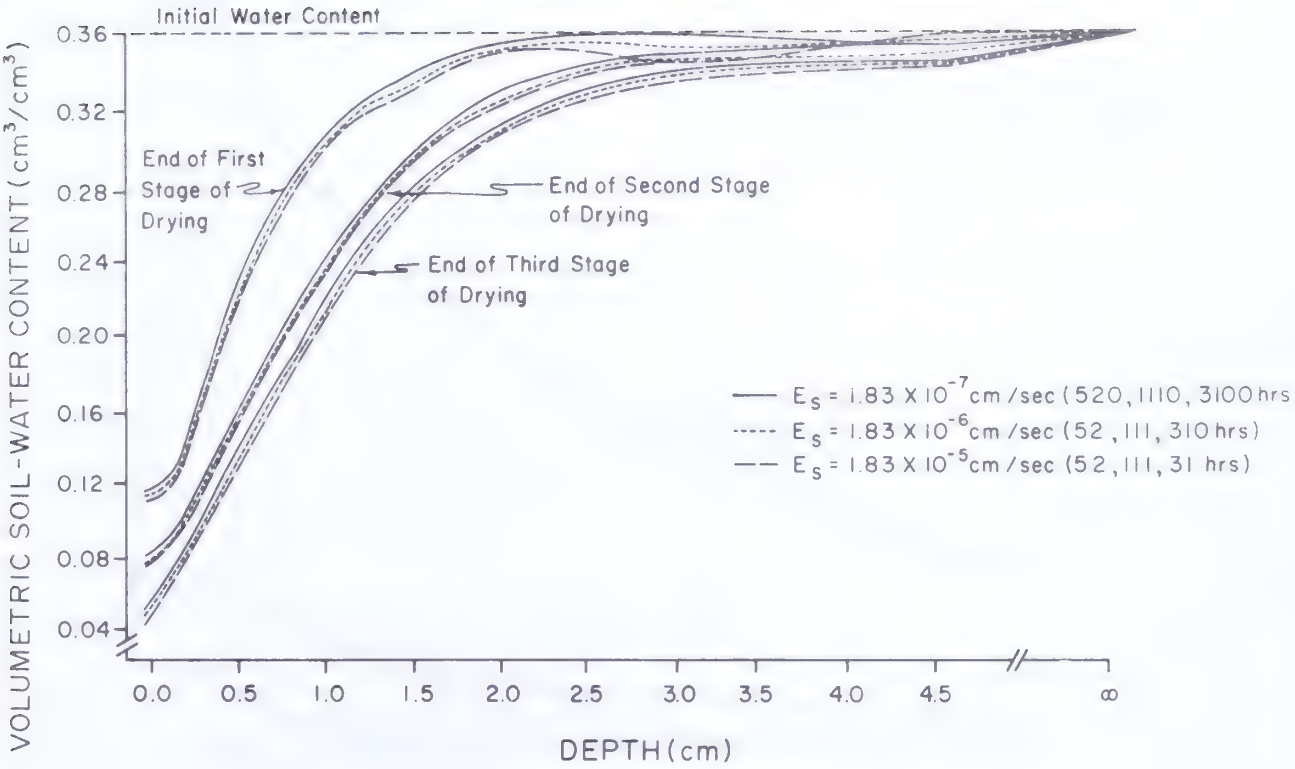

Fig. 3.1. Soil-water content profiles at the end of each stage of drying for evaporation rates of 1.83×10^{-5}, 1.83×10^{-6} and 1.83×10^{-7} cm/sec.

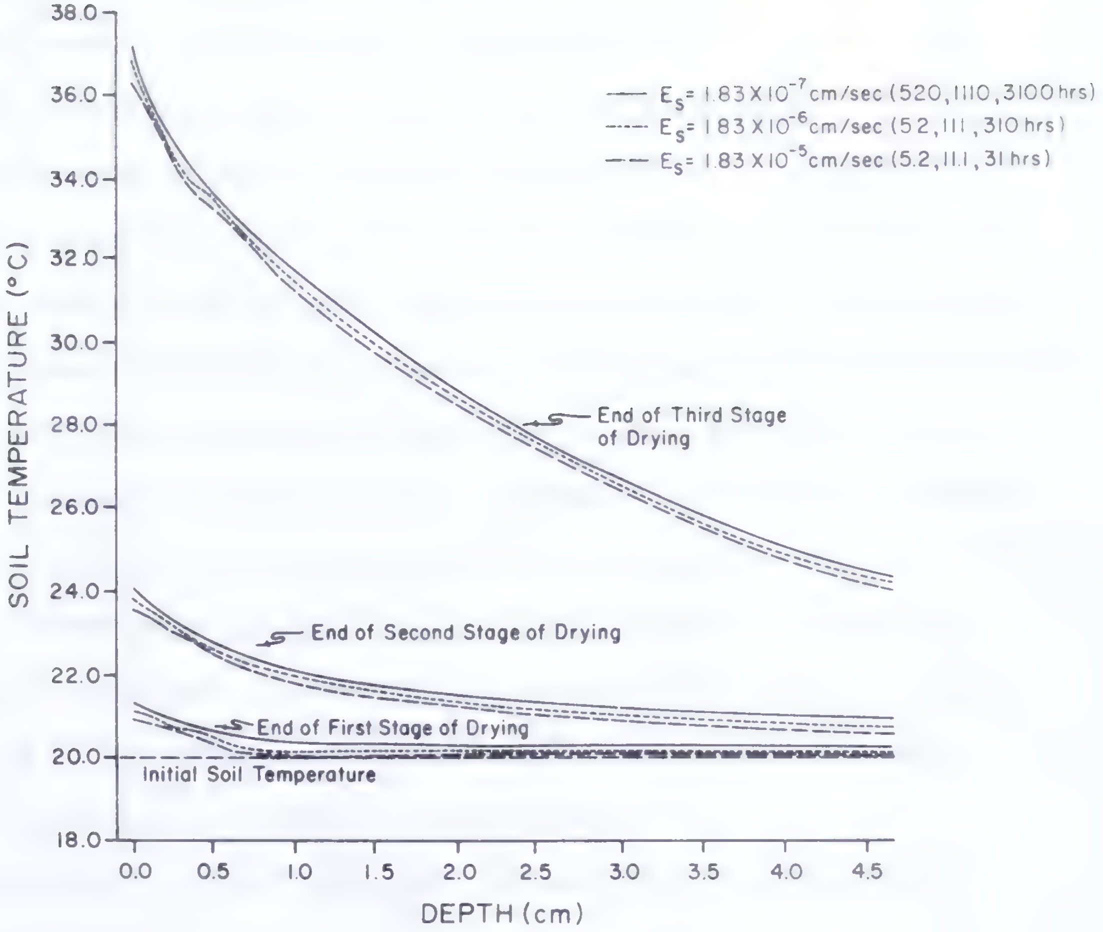

Fig. 3.2. Soil-temperature profiles at the end of each stage of drying for evaporation rates of 1.83 x 10^{-5}, 1.83 x 10^{-6} and 1.83 x 10^{-7} cm/sec.

4. Dimensional Group Analysis

The study of different physical phenomena may be approached by two different methods of investigation. Both methods yield different quantitative irregularities describing the phenomena under investigation. The first method is one of experimental investigation whereas the second is distinguished by a prior consideration of the problem. The chief inadequacy of the first method of investigation is the restricted value of the results. The results of any given experiment cannot necessarily be employed in connection with the same phenomenon observed in a different environment. Furthermore, to sample the spectrum of experimental conditions is a practical impossibility.

The alternate method is to develop, analyse and solve the differential equations describing the processes under consideration subject to boundary and initial conditions. These equations appropriately model the interaction between the medium within which the phenomenon is operative and its surroundings. These analyses can best be studied and extended by means of dimensional group analysis. Dimensional analysis is a powerful tool developed from a consideration of the dimensions in which each of the pertinent physical quantities involved in a phenomenon are expressed.

For example, for the first stage of drying if we consider the following transport equation:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[D_\theta \frac{\partial\theta}{\partial z}\right] + \frac{\partial}{\partial z}\left[D_T \frac{\partial T}{\partial z}\right] - \frac{\partial K}{\partial z} \qquad \text{....[4.1]}$$

This equation, because of its dimensional homogeneity, may be written in dimensional form as:

$$\frac{[\theta]}{[t]} = \frac{[D_\theta]\ [\theta]}{[z^2]} = \frac{[D_T]\ [T]}{[z^2]} = \frac{[K]}{[z]} \qquad \text{....[4.2]}$$

The square brackets indicate dimensions of the physical variables and not the variables themselves. Multiplying equation (4.2) through by [t] yields the following relationship:

$$[\theta] = \frac{[D_\theta]\ [t]\ [\theta]}{[z^2]} = \frac{[D_T]\ [T]\ [t]}{[z^2]} = \frac{[K]\ [t]}{[z]} \qquad \ldots.[4.3]$$

The above relationship yields four dimensionless groups; $D_\theta t/z^2$, $D_T tT/z^2$, Kt/z, θ. These four groups apparently reflect the effect of capillarity, temperature and gravity, respectively, on the θ-field development.

Extending this type of analysis to the boundary conditions and the energy transport conditions results in the following dimensionless groups:

$$\theta,\ \frac{D_\theta t}{z^2},\ \frac{D_T Tt}{z^2},\ \frac{Kt}{z},\ \frac{\lambda t}{Cz^2},\ \frac{C_\ell}{C},\ \frac{K(0,t)}{E_s},\ \frac{HT(0,t)}{T_a},\ \frac{T(0,t)}{T_a},\ \frac{LD_\theta(0,t)}{\lambda T_a},$$

$$\frac{LD_T(0,t)}{\lambda}$$

In all there are 15 variables, 11 dimensional groups and 4 fundamental dimensions namely, length, mass, time and temperature.

From the second and third stage of drying the only new dimensional groups that arise are

$$\frac{L_\rho}{C_1\ T},\ \frac{C_p}{C_1},\ \text{and}\ \frac{\rho_a}{\rho_v}\ .$$

In order to utilize the dimensionless groups that have been developed, their independence must be established. This is a basic requirement of the Buckingham Pi theorem. The validity of these groups can be determined according to a method described by Murphy (1950).

5. Model Evaluation

A. Mass Transport

Dimensional analysis indicates that the moisture fields should be in the form

$$F\left[\theta, \frac{D_\theta t}{z^2}, \frac{Kt}{z}, \frac{D_T Tt}{z^2}, \frac{K(\theta(0,t))}{E_s}\right] = 0 \qquad \ldots .[5.1]$$

The customary approach to the determination of the form of these functions would be for example, with respect to the function F, to hold all variables but two constant. One of these two would be considered a dependent variable. An examination of the relationship existing between these two variables as predicted by the model would then be made. This process would be repeated for several different sets of the variables held constant so that level surfaces could be developed and the influence of several variables on the chosen dependent variable or dimensionless group could be determined.

For the problem at hand, this approach is not used since the values of some of the dimensionless variables cannot in general be held constant but must take on values determined by the physical mechanisms involved in the transport problem.

However, the function F may be investigated in the earlier stated manner, by ignoring the temperature gradient and gravitational potential gradient induced mass transport on soil-water content. The two groups Kt/z and $D_T Tt/z^2$ in this situation do not then appear in equation (5.1) above.

The function F may then be rewritten in the form

$$\frac{D_\theta t}{z^2} = f \left[\theta, \frac{K(\theta(0,t))}{E_s}\right] \quad \text{....[5.2]}$$

A plot of the variable $\frac{D_\theta t}{z^2}$ as a function of the soil-water content θ for the three stages of drying for three different evaporation rates is shown in Fig. 5.1. The figure includes those cases when the groups $D_T Tt/z^2$ and Kt/z are both zero and each zero. This is comparable to ignoring the thermally and gravity induced flow, thermally induced flow and gravity induced flow.

Level curves of $D_\theta t/z^2$ as a function of θ for fixed values of $K\left[\theta(0,t)\right]/E_s$ are included in Fig. 5.1. It can be seen that for

$$0.12 < \theta < 0.25$$

and

$$2500 < \frac{D_\theta t}{z^2} < 8000$$

these level curves appear to coincide with the $D_\theta t/z^2$ versus θ curves within a soil-water content range of ±1.5 percent, whether or not $D_T Tt/z^2$ or Kt/z or both $D_T Tt/z^2$ and Kt/z are identically zero.

Thus, for this range of θ and $D_\theta t/z^2$, the relationship

$$D_\theta t/z^2 = f(\theta) \quad \text{....[5.3]}$$

presented in Fig. 5.1 as curve I or curve II may be employed to describe the soil-water content field.

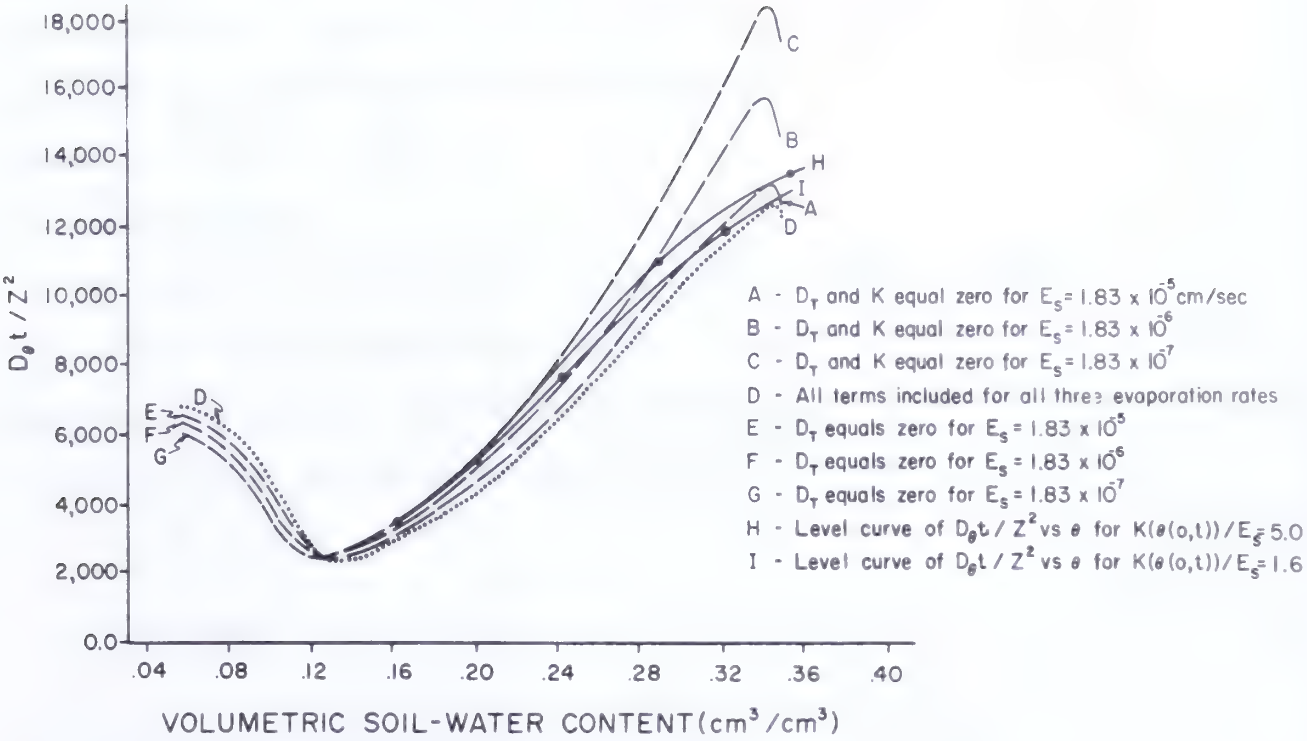

Fig. 5.1. Dimensionless groups, $D_\theta t/z^2$ as a function of soil-water content.

The behavior of the groups Kt/z and $D_T Tt/z^2$ as functions of soil-water content are presented in Fig. 5.2 and Fig. 5.3, respectively. The graphs are for three stages of drying at three evaporation rates. From Fig. 5.2, it is evident that Kt/z has little effect on the $D_\theta t/z$ relationship in the previously specified range since it is almost zero over this range. From Fig. 5.3 it is apparent that $D_T Tt/z^2$ is not small in magnitude. $D_T T/z^2$ takes on a minimal value in a range of soil-water content of $0.12 < \theta < 0.14$.

B. Energy Transport

The temperature fields may be investigated in a manner similar to that for the soil-water content fields. A plot of $\lambda t/Cz^2$ as a function of normalized temperature $(T(z,t)/T_{\text{initial}}$ for all three evaporation rates and all three phases of drying is given in Fig. 5.4.

For the range

$$\frac{\lambda t}{C_1 z^2} < 12{,}000 ,$$

it appears the simple Fourier-Kirchoff model for heat transfer is applicable. That is, the convective components of heat transfer are not significant in this region.

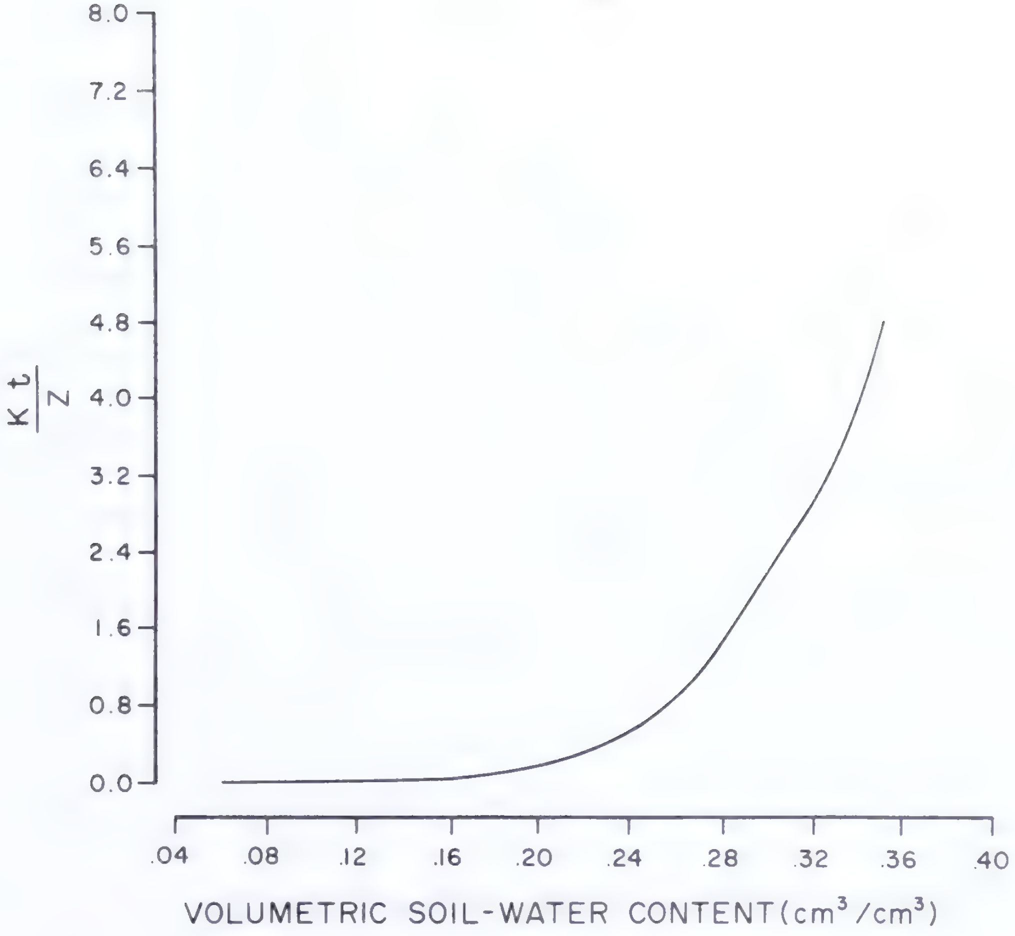

Fig. 5.2. Dimensionless group, Kt/z as a function of soil-water content for all three evaporation rates.

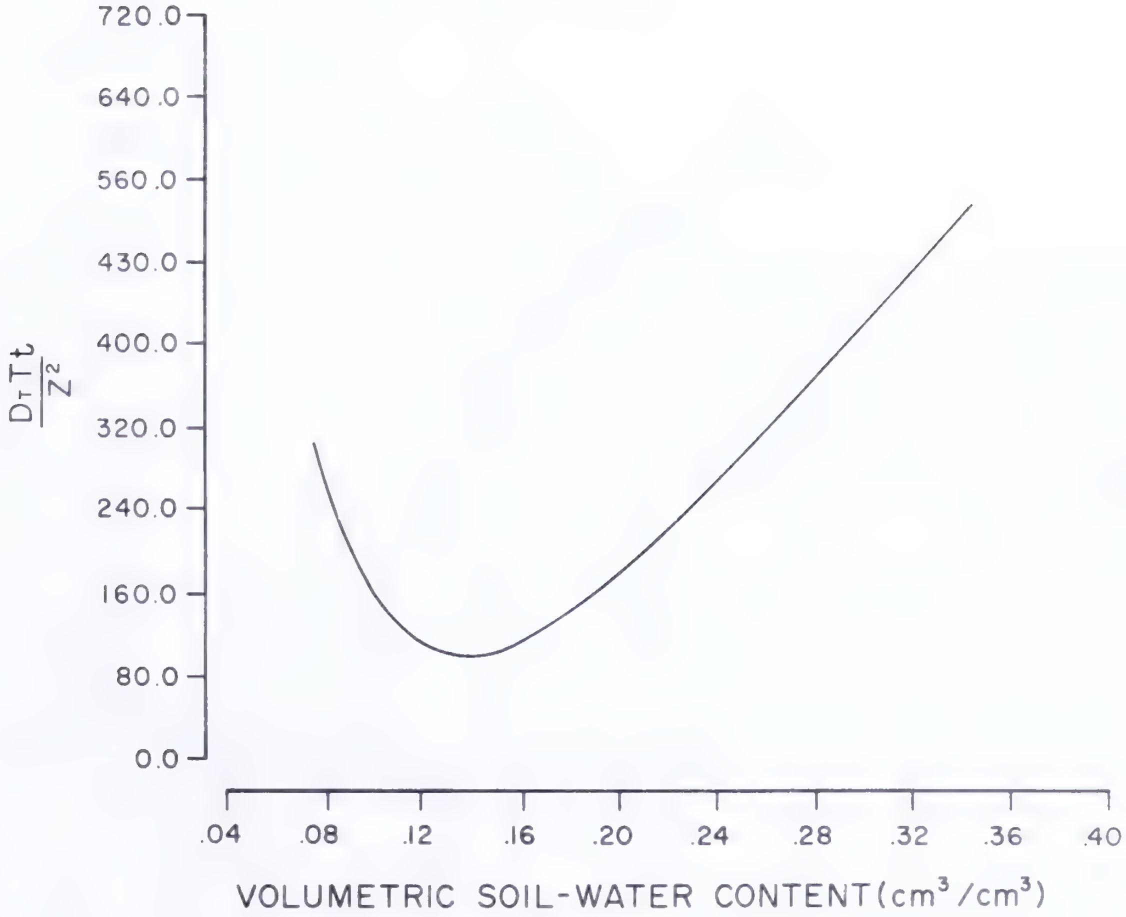

Fig. 5.3. Dimensionless group, $D_T Tt/z^2$, as function of soil-water content for all three evaporation rates.

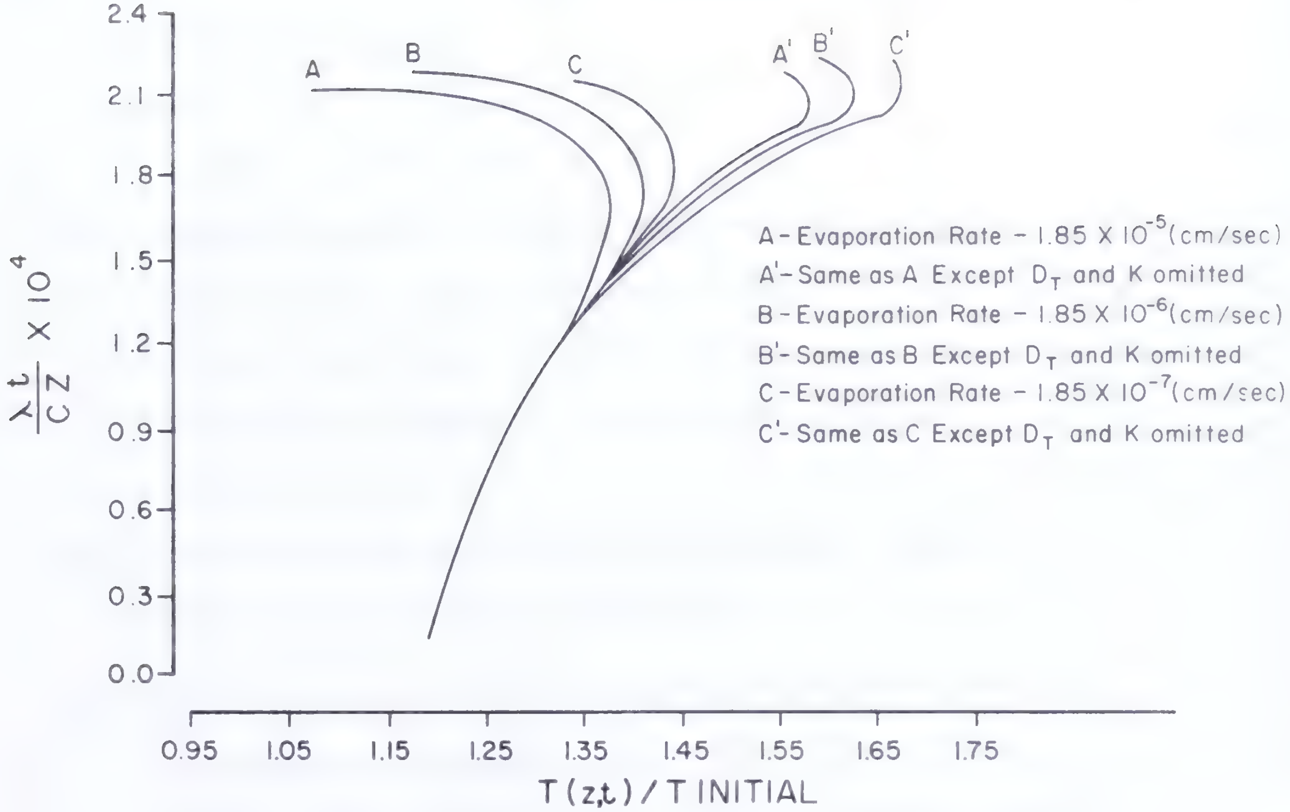

Fig. 5.4. Dimensionless group, $\lambda t/Cz^2$ as function of normalized temperature, $T(z,t)/T_{initial}$.

C. Summary

The preceding on model evaluation may be summarized as follows:

(i) For all evaluation rates, the region of applicability of the isothermal capillary transport model is when

$$0.12 < \theta < 0.25$$

and

$$2500 < D_\theta t/z^2 < 8000$$

(ii) The capillary isothermal mass transport model predicts soil-water contents within a soil-water content range of ±1.5 percent by volume of those predicted when thermal and gravitational effects on transport are included for soil-water contents in the range of $0.12 < \theta < 0.25$.

(iii) Gravitational effects are minor for soil-water contents less than 25 percent and for $0 < \frac{Kt}{z} < 0.6$.

(iv) Thermal effects on the soil-water content field are minimal in the range of soil-water content from twelve to fourteen percent. This range corresponds to the approximate value of one hundred for the group $D_T \frac{Tt}{z^2}$.

(v) The simple heat transfer model is applicable in the range of $0 < \lambda t/C_1 z^2 < 12{,}000$.

6. Further Applications

A mathematical model has applications other than the delineation of relative importance of modes of mass and energy transport during the drying process as previously described. The model can be used as a basis to predict: (1) crop response to nitrogen fertilizer under different soil and weather conditions since nitrate movement in soils is closely associated with water movement. (2) Salt accumulation and movement under dryland and irrigated conditions. (3) Effect of stones and their removal on soil water evaporation and relocation. (4) Seed environment relative to moisture, temperature and depth at the time of planting.

Dynamic models have been developed (Greenwood, 1974) which represent important processes such as leaching of nitrate through soil and nitrate uptake by plant roots. These models were used to forecast the effects of different weather conditions and cultural practices on (1) the nitrogen responses of test crops, (2) the general shape of the response curve of the distribution of rainfall during the growing season, (3) the age of the plant, (4) the depth of fertilizer incorporation, and (5) the application of the nitrogen partly as a top dressing instead of entirely as a base dressing.

Greenwood's model has been successfully applied to develop a strategy for nitrogen fertilizer practice for lettuce in the United Kingdom. It was found to be broadly in agreement with the results of fertilizer experiments on growers holdings. Similar studies have just been initiated at Swift Current for a wheat crop. Previous studies have shown that correlation methods are not adequate to describe natural processes.

Soil salinity, particularly under dryland farming practices, has become a problem of major concern. Both Alberta and Saskatchewan are attempting to resolve the cause of dryland areas which are going saline. Various theories have been postulated as to the possible causes. One suggestion made is that summerfallowing, particularly when used in a two-year rotation, may result in cultivated areas going saline. A research-demonstration site in Southwest Saskatchewan has been selected for which an attempt will be made to model the soil-water flow system and thus gain an understanding of the cause of dryland salinity.

The effect of stones and their removal on soil characteristics has been investigated by Hauk (1970) using a similar mathematical model as previously described. He has shown that the only beneficial effect a stony soil may have is increased infiltration of rainwater which conserves moisture and reduces erosion. The changes in thermal conductivity resulting from stone removal were also found to be relatively insignificant when considering soil temperatures. Stone removal also produced negligible influence on the drying of soils.

Plant physiologists (Walker, 1970) have suggested optimum moisture and temperature conditions which are conducive to plant germination. With a model that adequately describes moisture and temperature it is possible to investigate the most suitable seeding dates based on historical data. For example, Hauk (1970) has estimated periods of suitable soil moisture and temperature conditions for soils of the Northeastern United States.

References

FISHER, E.A. 1923. Some Factors Affecting the Evaporation of Water from Soil. J. Agr. Sci. 17: 407-419.

GREENWOOD, D.J., WOOD, J.T., CLEAVER, T.J. 1974. A dynamic model for the effects of soil and weather conditions on nitrogen response. J. Agric. Science, Vol. 82, 455-467.

HANKS, R.J., GARDNER, H.R. and FAIRBOURN, M.L. 1967. Evaporation of Water from Soils as Influenced by Drying with Wind or Radiation. Soil Sci. of Amer. Proc. Vol. 31, No. 5.

HAUK, R.W. 1970. Soil Temperature and Moisture Fields Predicted by a System of Coupled Equations. Unpublished Ph.D. Thesis, Cornell University, Ithaca, N.Y.

KEEN, B.A. 1914. The Evaporation of Water from Soil. J. Agr. Sci. 6, 456-475.

LEMON, E.R. 1956. The Potentialities for Decreasing Soil Moisture Evaporation Loss. Proc. Soil Sci. Soc. Amer. 20: 120-125.

PENMAN, H.L. 1940. Gas and Vapour Movement in Soil I. The Diffusion of Vapours Through Porous Solids. Journal of Agricultural Science 30: 438(1940).

PHILIP, J.R. 1957. Evaporation and Moisture and Heat Fields in Soils. J. Meteorology, Vol. 14, No. 4.

PHILIP, J.R. and D.A. DE VRIES. 1957. Moisture Movement in Porous Materials under Temperature Gradients. Trans. Amer. Geophys. Union, 38: 222-232.

WALKER, J.M. 1970. Effects of alternating versus Constant Soil Temperatures on Maise Seedling Growth. Soil Sci. Soc. Amer. Proc. 34: 889-892.

MINUTES OF THE
ALBERTA SOIL SCIENCE WORKSHOP

December 3, 1974.

INTEGRATING SOIL DISCIPLINES IN A MANAGEMENT PROGRAM

Dr. C. F. Bentley presented a summation of statements and quotations from each of the five speakers. The presentation focused the attention of the audience on the main topic of management as seen from five disciplines.

We have difficulty telling people in other disciplines what we are doing. We should be able to tell them that we are making the best use of what we have at our disposal.

Reference was made to the developments at the World Rice Research Institute in developing rice. These developments were made with a team effort. We should be able to make a similar contribution with a team approach with regard to management information for Alberta farmers.

It is necessary to sift out what is not necessary and combine what is useful and get a lot more information for a specific farmer in Alberta with a specific problem.

We must still seek out more information, but as a group (team) we have not given enough consideration to all the aspects for the farmer.

This, in brief, is from notes made during Dr. Bentley's presentation since it was given as a challenge to the audience to stimulate discussion which was as follows:

Chairman - A. Sorensen as Discussion Leader.

The five papers and the comments by Dr. C. F. Bentley have covered in a model form, the principles involved in Integrating Soil Disciplines in a Management Program. There are many branches and disciplines left out of this discussion such as Pathology, Physiology, Entomology, Plant Disease, etc.

"How do we put this together into solving a specific problem for a specific farmer?"

Audience Comments:

This is an impossible question in our present state of knowledge. The question was re-worded: "Can we form a team to put this information together for the farming public?"

- The approach to management in the present context may be looking at too many factors. Maybe we should look at a few factors such as moisture, temperature, nutrients, and availability of nutrients, and put these together as simpler factors and broad parameters and work toward specifics.

- The (better) farmer is at present, looking at all these and doing a lot of interpretation from the scientists, some times better than the scientists are themselves.

- The model must be set up for him with his problem in the model. Maybe we are trying to use averages too often.

- Maybe we should use the outstanding farmer and form a model around what he is doing.

- These farmers (outstanding) are making their own model from the information available, but the neighbouring farmers, who are not doing as well, are not able or don't realize that a model is to be built for their farming enterprise.

- Farmers know a lot more than some give them credit. If they are given a profit-oriented incentive, they can make use of much stored data.

- How do we get extension information to the farmer in a package? Should be able to program the whole thing to him.

- Maybe we are too specialized. Should back off some and be able to give a fair amount of information from our own discipline as well as others.

- We could quantify the inputs that the farmer wants and have the Soil Test Lab feed the information back to him.

- This winds up with us bombarding the farmer with a lot of information and he has to sift through the mass to get out what he needs.

- Could consider setting up various levels of management through a "Productivity Lab" to go out from there for various disciplines.

- The frustration we experience is manifested more in the students (University) whom we turn out. They are more specialized than many of those who graduated years ago.

- Is there a Soil Management course being taught at the University? - Yes there is one being taught at present.

- We are extending ourselves fairly well now, but we want to help the farmer to go a little further.

- The better farmer has been doing the little bit extra each year for 10 or 15 or 20 years, such as seeding at the right time, cultivating a little deeper, fertilizing a little higher. The end result is he has several years of a little more, and ends up with higher yields, etc. The other farmers must then try to catch up, but can't without all the back history and several years.

- May-be fertilizer should be distributed only to the farmers who have a Soil Test.

Discussion was drawn to a conclusion and thanks extended by the Chairman to the speakers for their contribution and to the audience for their participation.

EDITORIAL NOTE TO 1974 SOIL SCIENCE WORKSHOP

The discussions this afternoon have covered a wide scope of management factors and how each may, ideally, form a model. What appeared to come forward from this was that thus far in time (up to 1974) we have assisted the farmer to better manage his soil towards maximum production. We did this individually and accidentally for the various disciplines, and we have been

able to account for 50 to 65% of the variability in production on Alberta soils. We are now looking to the future to go that "extra mile". The higher we attempt to push production, it becomes harder and harder to move production upward. It is essential to go this "extra mile" from a team approach. This team must be interdisciplinary in nature, and will be in keeping with our future objective of maximum assistance to the specific farmer on the land and for his specific problem. This means drawing out all information from all the sources, sifting out impertinent data, and compiling it toward a data bank for every-one to use when talking and working with specific farmers and their problems.

NOMINATIONS FOR 1975

A. Sorensen as Chairman asked for nominations for two positions. One for Vice Chairman Elect, with this position being vacated by J. Carson who is leaving for Indonesia, and one for Secretary.

E. Berg nominated J. Beaton as Vice Chairman. A. Hennig moved nominations cease. Seconded by J. D. Lindsay. CARRIED.

K. Nielsen nominated B. Toews for Secretary. T. Peters moved nominations cease. Seconded by D. MacKay. CARRIED.

Chairman invited the audience to suggest topics for the 1975 Soil Science Workshop.

- Suggestion by K. Nielsen that we consider one aspect of this year's topic of Climate - there are many aspects of this part that are changing so much. Is there really a change in weather and climate patterns? What practices may help to get the crop off earlier?

Location of 1975 Soil Science Workshop.

- Moved by Pittman that the Executive investigate the possibility of holding the Workshop in Calgary.

A. Sorensen as Chairman of the 1974 Soil Science Workshop formally introduced W. Rice as Chairman of the 1975 Soil Science Workshop.

W. Rice, as Chairman, formally declared the meeting adjourned.

Respectfully submitted,

J. A. Carson, P.Ag.,
Secretary.

JAC:bp

ATTENDANCE LIST

R. G. Bell	Agriculture Canada	Lethbridge
C. F. Bentley	University of Alberta	Edmonton
E. Berg	Cominco Limited	Edmonton
B. Black	Sherritt Gordon	Fort Saskatchewan
W. Borden	Alberta Agriculture	Lethbridge
R. Cairns	Agriculture Canada	Vegreville
J. Carefoot	Agriculture Canada	Lethbridge
M. Chaudbury	Vermilion College	Vermilion
G. Coen	University of Alberta	Edmonton
J. Crepin	University of Alberta	Edmonton
L. C. Davison	Alberta Agriculture	Edmonton
E. Dobko	Imperial Oil Limited	Edmonton
S. Dubetz	Agriculture Canada	Lethbridge
I. K. Edwards	Cdn. Forestry Service	Edmonton
H. A. Friesen	Agriculture Canada	Lacombe
A. W. Goettel	Alberta Agriculture	Edmonton
G. Greenlee	Alta. Research Council	Edmonton
R. E. Harris	Agriculture Canada	Beaverlodge
E. R. Heinrichs	Agriculture Canada	Edmonton
A. M. F. Hennig	Agriculture Canada	Beaverlodge
J. Hermans	Alberta Agriculture	Lethbridge
R. Heywood	Alberta Agriculture	Lethbridge
L. Hodgins	A.S.F.T.L.	Edmonton
W. Holland	Cdn. Forestry Service	Edmonton
A. A. Kjearsgaard	University of Alberta	Edmonton
D. Klaffke	Alberta Wheat Pool	Calgary
S. Kocaoglu	University of Alberta	Edmonton
K. K. Krogman	Agriculture Canada	Lethbridge
D. H. Laverty	A.S.F.T.L.	Edmonton
R. Leitch	Agriculture Canada	Beaverlodge
G. Lesko	Cdn. Forestry Service	Edmonton
J. D. Lindsay	University of Alberta	Edmonton
D. C. MacKay	Agriculture Canada	Lethbridge

S. Malhi	University of Alberta	Edmonton
D. K. McBeath	Agriculture Canada	Lacombe
D. McCoy	Alberta Environment	Lethbridge
L. McCulley	Western Co-operative Fertilizers Limited	Calgary
C. McKenzie	Alberta Agriculture	Brooks
B. McGill	University of Alberta	Edmonton
K. Moreney	University of Alberta	Edmonton
R. W. Nelson	Alberta Agriculture	Red Deer
W. Nicholaichuk	Agriculture Canada	Swift Current
M. Nyborg	University of Alberta	Edmonton
M. Oosterveld	Agriculture Canada	Lethbridge
P. Parish	Western Co-operative Fertilizers Limited	Medicine Hat
B. Paterson	Alberta Agriculture	Lethbridge
D. C. Penney	Alberta Agriculture	Edmonton
T. W. Peters	University of Alberta	Edmonton
W. Pettapiece	Agriculture Canada	Edmonton
U. J. Pittman	Agriculture Canada	Lethbridge
E. S. Redshaw	A.S.F.T.L.	Edmonton
W. Rice	Agriculture Canada	Beaverlodge
P. Sandberg	Agri-Analysis	Lethbridge
C. D. Sawyer	Alta. Lands & Forests	Edmonton
M. Scheelar	University of Alberta	Edmonton
C. Schuring	Alta. Lands & Forests	Edmonton
B. Siemens	Agriculture Canada	Fort Vermilion
D. Smith	Agriculture Canada	Lethbridge
A. K. Sorensen	Alberta Wheat Pool	Calgary
W. H. Toews	Alberta Agriculture	Edmonton
H. Vander Pluym	Alberta Agriculture	Lethbridge
D. Walker	Agriculture Canada	Lacombe
G. R. Webster	University of Alberta	Edmonton