THE USE OF LAND CHARACTERISTICS IN CROP SCIENCE WITH PARTICULAR REFERENCE TO THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

The importance to crop growth of forces generated by land — climate and soil — is stressed. Outlined are some of the benefits which accrue from the use of ecotopes (classes of land, each uniform with respect to climatic type and soil series) in agronomic research and extension. By preparing and using climatic maps, and by using existing soil parent material maps to facilitate series recognition, a method is suggested for the easy identification of the many and varied ecotopes of the South African Sugar Industry.

Introduction

By studying the physiology of crops and the demands that they make upon the environment when grown successfully, and by shedding light on the forces that climate, insect pests, diseases, weeds and soil exert on crop growth, man is increasingly able to modify nature so that its forces can be channelled to provide more of what the crop requires. By identifying these forces and then finding ways of modifying them to the advantage of the crop, an advance has been made from the passive acceptance of everything that nature has to bestow, to a science in which nature is regarded as an accomplice rather than a master.

Many of the forces that nature brings to bear on crops are generated by land — climate and soil. In this paper a method is suggested for the easy manipulation of land data in the Sugar Industry, which comprises a wide range of soils and climates. Some of the advantages, which flow from using a knowledge of land in crop science, are given in order to highlight the necessity for studying and systematically cataloguing the land characteristics that affect crops.

Ecotopes and their significance in the Sugar Industry

Climate and soil

It is a truism that an agricultural treatment found to work in one place is not always applicable at another. The reason for this is that different natural forces prevail at different places. While some treatments, for example rendering seed cane disease-free by heat treatment, are applicable everywhere, others are not, as is the case with fertilizer treatments and the location of varieties. Thus, the land itself influences the way in which we use it for crop production and the success we have in doing so. The forces which land exerts on the crop spring from climate and soil and from interactions between the two.

The importance of climate to crop growth is widely appreciated and requires no amplification here. However, a few comments on the role of soil and topography may be pertinent. These modify the effect of climate by influencing:

(i) the percentage rainfall absorbed and the percentage runoff;
(ii) the percentage rainwater held in the root zone;
(iii) the percentage absorbed rainwater in the root zone that the soil will release to the plant;
(iv) the rate at which soil releases available moisture to the plant (compared with the transpiration rate);
(v) the rate at which the roots are permitted to explore the soil for moisture;
(vi) the "irrigation" of the crop or damaging wetness through watertable build-up in subsoils;
(vii) temperature.

Soils determine the rates of fertilizer application due to their nutrient supplying and immobilizing powers. They also affect crop growth by virtue of:

(i) alkalinity and acidity,
(ii) toxicities,
(iii) the inability of some to supply trace elements, the lack of which is difficult to detect,
(iv) salinity,
(v) their ability to prevent applied fertilizers being leached out of the root zone,
(vi) their biological constitution, including pest populations, and
(vii) the effect of interactions, at present difficult to gauge, of the many properties of soil.

If we were to consider the effect of climate alone on the growth of crops, we would get apparently inexplicable differences in response to a given treatment on land which, during a particular season, was subjected to a uniform climate. Conversely, we could find response differences on one and the same kind of soil, because it is found at a number of places which, during a particular season, may be subjected to different climatic regimes. Climatic and soil forces, together with those resulting from the interaction between the two, must therefore be considered in order to assess the net forces which nature exerts on a crop at a particular site. To be useful in crop science, land must be defined in terms of climate and soil. Collectively, such a grouping, describing a particular kind of habitat within a region, can be called an *ecotope* (Henderson *et al*, 1963). In the context of this paper an ecotope has a uniform climate and soil; it differs from other ecotopes in that its climate and/or soil is different. The greater

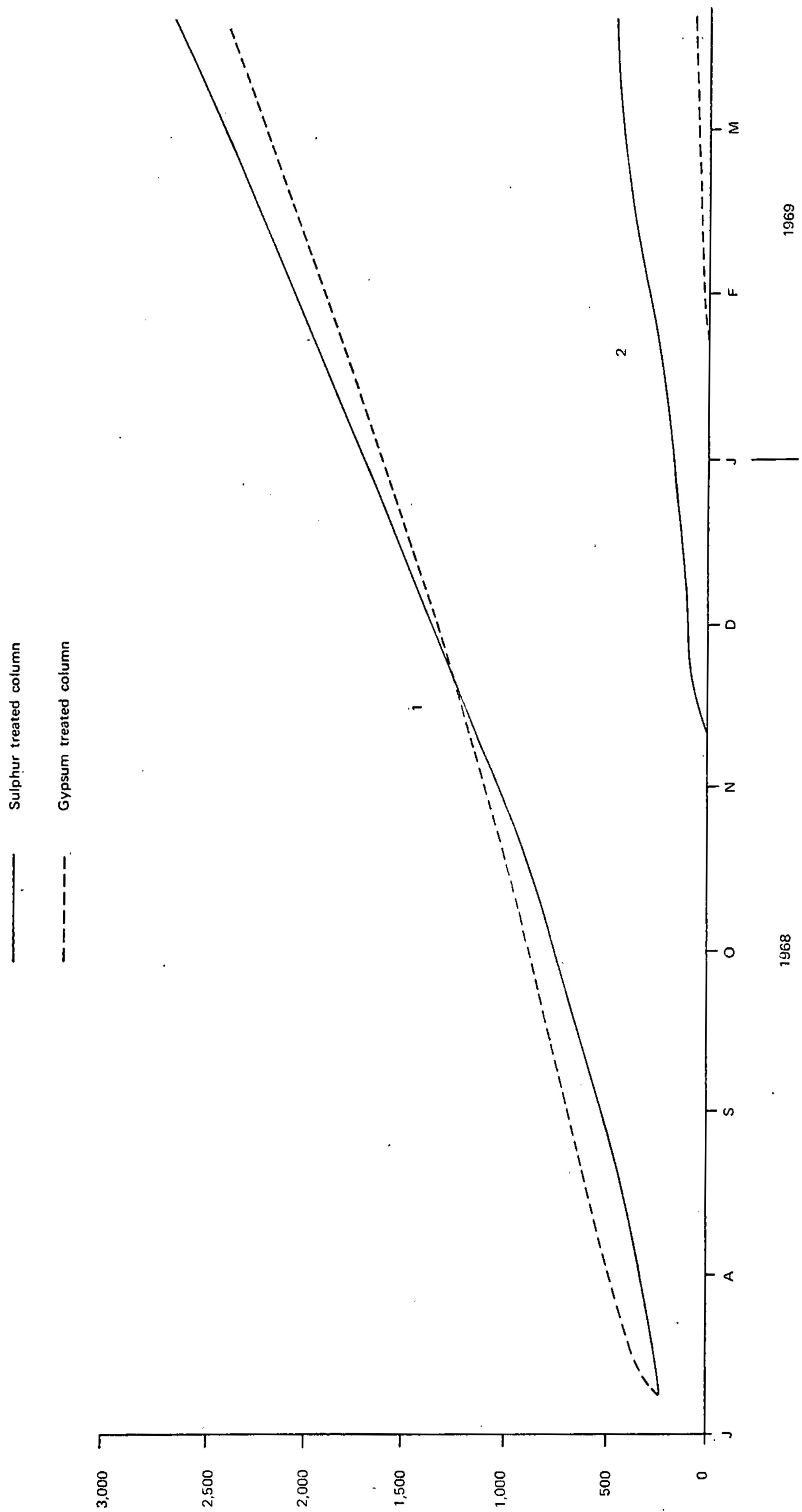

FIGURE 2: Amount of water added (1) and volume of leachate collected (2) from columns of saline-alkali soil treated with sulphur and gypsum.

the variability in climate and soil, the more urgent is the need for attention to be directed at their effect on crop growth.

The variability of climate and soil in the Sugar Industry

If the climate and soil of the South African Sugar Industry were each more or less uniform, the influence of land on management and yield would not merit a particularly large proportion of research attention, after completion of the initial surveys and investigations. However, the climate embraces hot semi-arid, warm sub-humid, warm humid, and cool sub-humid zones where frost is not uncommon. Apart from large depth and slope variations, soils include the following:

(i) red and grey, medium-grained sands;
(ii) black, fertile, heaving clays, occasionally saline;
(iii) moderate to very acid, porous, red and yellow soils, some aluminous and some humic;
(iv) dark coloured, fertile, usually shallow clays on shale;
(v) solonetz soils, occasionally saline;
(vi) neutral, fertile red clays;
(vii) wet gley soils, both clayey and sandy;
(viii) permeable, loamy soils with dense, clayey subsoils;
(ix) extremely fertile, dark coloured alluvial soils.

With such a variety of ecotopes, not only do climate and soil merit considerable attention, but agronomic communication in respect of suitable treatments for land is hardly possible without a proper statement of the kind of land (ecotope) to which treatments are to be applied. However, with the exception of tests carried out in order to provide nutritional recommendations, the character of land in the Sugar Industry is not normally used for making treatment recommendations.

Storage of treatment data

A store of recommendations on how to grow sugarcane should consist first of a statement of those treatments which are not affected by ecotopic characteristics and are therefore automatically applicable at every site throughout the Industry.

Those treatments, the effects on cane growth of which depend on ecotopic factors, must necessarily be stored in terms of the relevant land characteristics. If these treatment data are to be drawn from the store and applied in the field by extension staff, then the latter must be able to identify — as quickly and as easily as possible — the ecotopic characteristics which determine whether or not a treatment is applicable at a certain site. For example, if deep soil disturbance is beneficial only on soils X, Y and Z, then the extension officer must be able to recognize these soils in the field.

Defining ecotopes in the Sugar Industry

The manner in which ecotopes are defined depends on the nature of the land, the uses to which a knowledge of land will be put, and on the kind and amount of information which has been collected. These considerations suggest a method, detailed below, for defining the soil component of land in the Sugar Industry. The climatic component is discussed in principle rather than in detail.

Climatic types

The best way of presenting climatic types for use in the field is in map form. Such a map cannot, however, tell us, with any precision, what the rainfall will be during the coming season or how it will be distributed; nor will it tell us exactly what temperatures will prevail. A climatic map is drawn on the basis of what has happened in the past. Based on an accumulation of data, the climatic map is an expression of climatic probabilities and gives the probable frequency with which a number of climatic conditions are expected to prevail over a piece of land. It allows us to make predictions that fall within limits of accuracy which have managerial and economic significance.

Although what might be considered a good climate map of the Industry is at least a long term project, it should be possible to construct a useful approximation at present. This may be done by using all available data and maps, modified by the experience of extension staff who will be able to pinpoint noticeably wet and dry areas, locations where frost has occurred, and mistiness. In this way, a climatic model could be prepared which could be modified (by observation and the judicious placement of meteorological stations) with the progress of time. Without such a model as a starting point, we shall continue to make little progress in using a knowledge of our varied climate in cane technology.

Soils

The following are some of the methods that have been suggested for quickly describing soil conditions important to crop growth. The third method is suitable for the Sugar Industry.

(i) *Over-simplified methods*. These have not fulfilled their function because they have failed to cater for many soil conditions that affect crop growth. An example is the suggestion that only depth is of any consequence. Another is that depth, texture and slope are all that it is necessary to know about soil. These shortcut assessments all lead to apparently inexplicable response differences caused by soil conditions not included in the particular method of soil characterization. This approach of "making do with the barest minimum" is understandable as it signifies a human reluctance to deal with things of a complex nature. It is hardly permissible, however, for an applied scientist, who must progress through improved understanding.

(ii) *The soil code*. A code is a list of properties which describe soil and is used in the following way. Let us assume that we do not know of the existence of Rydalvale, Shortlands, Fernwood and Clansthal soils (Beater, 1957, 1959, 1962) and that all we know of the soil of the Sugar Industry is that it is a mantle in which conditions vary from one place to another. An experiment site, chosen for its general uniformity, is coded, that is, described in terms of effective depth, surface texture, permeability of upper subsoil, permeability of lower subsoil, material limiting effective depth, colour of upper subsoil, texture of upper subsoil, slope, erosion hazard, parent material, pH, wetness, salinity and so on. Having done this, the result of the experiment, assuming it is a soil-dependent one, is applicable wherever this combination of soil conditions is found under a comparable climate. However, in order to determine whether the result is applicable at a certain site, the extension officer must go through the whole rigmarole of determining each of these items. The tediousness of the procedure is a great deal worse if the extension officer is obliged to await the results of lengthy analytical procedures, such as those for available moisture capacity and aluminium status. In addition to being tedious, the method is liable to subjective error: two people, for example, giving different permeability ratings to the same soil.

(iii) *Soil series*. The number of observations that must be made by an extension officer in the Sugar Industry to determine how similar a soil is to that at an experiment site — and hence the extent to which the experimental result is likely to be applicable — can be greatly reduced in the following way.

It is well known that in the field, bodies of soil occur each of which has a high degree of homogeneity; that is, the range of each property (for example, available moisture capacity) is narrow. The black (Rydalvale) and red (Shortlands) clays from dolerite are good examples. Each is uniform for every property mentioned in the code *except slope, depth and, in rare instances, salinity*. Once we have done the necessary analytical work we shall know their wetting and drying curves, their available moisture capacities, their texture, structure and colour. We know that they are never very acid and never high in aluminium. Without having to make any measurements, we know a great deal about these soils whereas, using the soil code, a large number of measurements is required. If we can recognize these bodies of soil easily in the field, we have a method for rapidly and accurately identifying the soil character of land.

Five kinds of soil — or *soil series* as they have been called in South Africa — have been found in the Industry on Lower Ecca shale.

To permit easy identification of these distinct series, a short pamphlet is needed providing a colour photograph of each, details of its most important properties and a note on where it occurs[1].

The parent materials of soils found throughout the entire industry will soon be shown on maps. By glancing at a map and seeing "Lower Ecca", the crop scientist or extension officer immediately reduces his choice from a large number of series to only five. By using the photographs and brief descriptions in the pamphlet, it will then be an easy matter for him to choose which of the five series he is dealing with. However, as he also knows (Table I) that Mispah and Balgowan occur only in the moister grassland or forest regions of the Midlands, his choice in fact is reduced to only two. To choose between Mispah and Balgowan he must auger into the subsoil (where he will encounter either shale or a yellow, porous clay), a procedure he must adopt in any event to determine soil depth. Thanks to the spadework of Drs. B. E. Beater and R. R. Maud, who provided soil parent material maps for 60 per cent. of our Industry and identified most of the more important series, we are now within reach of a method for rapidly and accurately establishing the soil character of land.

[1]This can be done for the soil series on each parent material.

TABLE I

Soil series derived from Lower Ecca shales

Coast Lowlands and Midlands Thornveld	Uplands	*Milkwood:*	shallow, dark, base-rich clay on shale.
		Glengazi:	moderately deep, dark, base-rich clay upon a brown, base-rich clay subsoil.
	Vleis	*Phoenix:*	deep, dark, base-rich clay upon a grey, wet potclay.
Midlands grassland and forest	Uplands	*Mispah:*	shallow, grey, acid clay on shale.
		Balgowan:	a moderately deep, aluminous soil consisting of a dark, acid clay upon a yellowish brown, extremely acid, porous subsoil.

A full description of the soil character of an ecotope would be as follows:

$$\frac{S\ D\ G}{W\ N}$$

where S = soil series (e.g. Milkwood)
D = effective rooting depth
G = gradient or slope

and where W[2] and N[3] are wetness and salinity items.

Under non-irrigated conditions the description would usually involve the top line only, namely identification of the soil series and estimation of depth and slope.

It has been decided that the naming of soil series within the Sugar Industry will conform with the national nomenclature. This will enable research workers in the Sugar Industry to make use of soil and related research conducted elsewhere. The soil which Beater (1957) has called Shortlands, for example, is found throughout South Africa, where it is known also as Shortlands. Research conducted on it elsewhere will thus, through its name, be made readily available to the Sugar Industry. Should a new soil be found within the Industry that has been found and named elsewhere, it will be called by this name to promote the inter-regional exchange of research results.

Many of the properties of a series, such as Shortlands, that affect plant growth are known and can be measured. However, the net result of the interaction of all the properties of the Shortlands, a quantity that is difficult to gauge, has itself an effect on plant growth, and it is reasonable to assume that this soil effect will be the same wherever Shortlands is found under comparable climate. The same holds true both for other unknown properties of this series and for known properties which are difficult to measure. A possible shortcoming of this or any other method of characterizing soil, is that there may be soil conditions important to crop growth which vary independently of these bodies of soil. However, this eventuality, which would necessitate grid survey techniques, will certainly occur to a much lesser extent with this than with other methods of soil characterization.

The use of ecotopes in crop technology

The following are some of the uses to which clearly defined ecotopes can be put.

Determination of land capability and planning land use

Given a certain level of management[4], climate and soil will determine the capability or potential of the site for production of sugarcane. The soil series of a site is not a variable. Climate, however, varies from year to year and it is not therefore possible to state the potential of a site in terms of crop yield for a specified future season. It has been shown that a climatic type expresses the probable frequency with which a number of climatic conditions are expected to prevail at a specific site. If we have measured the potential of the site under these climatic conditions, then we can predict the probable frequency of yield, a consideration of managerial and economic significance. Land capability, or production potential, must therefore be expressed as a yield under given management, climate and soil. The prediction of potential, a consideration basic to planning, is made in terms of climatic predictions against a backdrop of specified soil and management.

Progress in our knowledge of land capability has an important implication for management: the more we find out about what the various ecotopes require for optimum plant growth, the greater will be the need for management to become more specific. An increase in the amount of informed management per acre will be necessary to satisfy the needs of individual tracts of land, and so maintain a steady yield increase on the land available for cropping. The latter is an important consideration once the opportunity for bringing new land under the plough has passed.

Planning research

Knowing the ecotopes within the Industry and our present state of knowledge regarding their capability, we can profitably plan research to deal with deficiencies in our knowledge of their capability, and in terms of conditions relating to the ecotopes which are known to be limiting. Research must be planned so that treatments, whose effect on cane growth depend on the quality of land, can be stored in terms of the relevant land characteristics. This may be done by restricting each investigation to a single ecotope or, if the effect of land is being measured, by ensuring that single ecotopes are used to represent differences in the quality of land. This land-orientated branch of research should be clearly distinguished from those investigations, the results of which are applicable irrespective of climate and soil type.

The applicability of research advances

A response to a treatment depends on certain elements of climate, soil and management. It may be possible at some time in the future to detail how each of the components of climate and of soil, both individually and in combination, affects crop growth. This would permit us to predict exactly what management techniques different kinds of land would require. Easily recognisable and intensively investigated ecotopes would greatly reduce the amount of work necessary to determine the required management at a particular site. Although progress has been made in this direction and although it is possible, on many occasions, to predict management on this basis, there remain instances of significant responses the reasons for which are not fully understood. Here, we are obliged to adopt the view that

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[2]Intermittent or permanent saturation and depth to material affected by free water.

[3]Conductivity of the saturation extract, pH and exchangeable sodium percentage.

[4]Maximum economic yield of a site is not a constant but varies according to factors such as market prices and production costs. Furthermore, maximum yield is not always equal to maximum economic yield. Because maximum economic yield is the yardstick of successful agriculture, potential should not be expressed as a single value, but rather as a function of management input.

the response will tend to become less significant as conditions move away from those under which the experiment was conducted. Soil series and climatic types enable us to gauge these ecotopic differences quickly. Finally, it is clear that responses have significance and can be acted upon only if the climate, soil and management conditions prevailing during the experiment are known. However, the tendency has thus far been to spend most effort in detailing, with great care, the conditions of management, but to neglect those pertaining to climate and soil.

Diagnosis

Production potentials are determined by properly directed research. This means that for a given soil and climate regime we know what treatments are required to achieve potential.

If optimum economic yields are not being realised at a certain site, the reason can be found by first eliminating all the treatments which affect yield irrespective of the soil and climate, and then by eliminating the treatments required on the specific ecotope. In this way, diagnosis, an important facet of extension, can be practised by scientific method rather than by intuition or a haphazardly applied rationale. Since diagnosis concerns what has already happened, problems connected with climate prediction do not arise.

Establishing extension priorities

Being able to identify ecotopes (that is, soil and climate) in the field and knowing what yields ought to be achieved on them, an extension officer can easily deduce whether attainable yields are being realised and, if not, why not. His attention is thus quickly focused on the reasons for low yields in his district, enabling him to determine priorities in his extension campaign.

Avoiding problems

A knowledge of our climatic types and soil series will help us to anticipate and guard against their associated problems including *inter alia:* sites where salinity is likely to become a problem under irrigation; areas where we can expect small or large responses to applied nitrogen due to variations in soil mineralizing powers; locations where we must be careful not to over-irrigate due to seasonal groundwater fluctuations and places where liming is likely to be needed. It is in this sphere that the Fertilizer Advisory Service may be assisted. Instances arise when a farmer needs a fertilizer recommendation without having had his soil tested. Clearly, this is best done if the ecotope (climate, soil), together with its capability and limitations, are known.

The control of living organisms

There are, no doubt, many insects and other organisms which occur more or less independently of climate and soil. However, ecological principles suggest that certain patterns of microbe, weed and insect distribution might be identifiable in terms of ecotopes. Where this is relevant, knowledge of the latter may materially assist in providing control, once the patterns have been discovered.

Determining land values

It has been mentioned that an extension officer must know the capability of land in order to decide whether improvements in production can be made. This knowledge is, of course, pertinent to the question of land values.

Alternate crops

The information contained in well-defined climatic types and soil series helps to ensure an easy changeover from one crop to another.

Ecotopes and a manual of sugar cane production

The Experiment Station should, in the near future, be able to define easily identifiable ecotopes. A suitable means can thus be provided for storing land capability data, and all data relating to treatments, the effect of which on cane depends on climate and soil. It is logical, therefore, that a statement of these data in a manual of cane production should be made in terms of the climatic types and soil series. Furthermore, a statement of the climate and soil classes themselves would logically precede the presentation of capability and treatment data in a manual.

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Discussion

Dr. Thompson (in the chair): Dr. Macvicar's paper is divided into two distinct parts. The first concerns the so-called ecotopes, and the second concerns the identification of a soil series on a particular site. Regarding ecotopes, what does Dr. Macvicar feel about the phase variation of such important soil characteristics as moisture holding capacity within a single soil series?

Dr. Macvicar: Phase variations exist but some unit has to be established if soils are to be classified logically. This unit is the soil series, and the soil properties which are of importance to crop production do not vary independently of soil series.

Mr. Tucker: Dr. Macvicar has talked about the importance of climate and soil in determining land capability, but the management factor should not be ignored.

Dr. Macvicar: It is important in the first instance to define the datum line from which we start, namely climate and soil, before introducing the management variable. As I have indicated, capability or potential is a function of land, the subject of this paper, and of management.

Dr. Sumner: We, in the Department of Soil Science at the University of Natal, have found some significant property variations in the topsoils of a single series. What steps should be taken to cater for these variations?

Dr. Macvicar: It is necessary firstly to ensure that the variations do in fact occur within one series, because series identification has not yet reached a very high standard. However, significant differences (for example, depth and possibly aluminium status) will undoubtedly occur within a series; a grid sampling technique would be required to show them on a map.

Mr. Wardle: Should an ecological factor not have been incorporated in the ecotope?

Dr. Macvicar: I think this would unnecessarily complicate the ecotope because most of the factors which determine plant distribution patterns are incorporated in the ecotope as it stands.

Mr. Wardle: Ecological variations indicate land differences important to the growth of plants of which sugarcane is one. I should have thought therefore that the distribution of plants would enable a significant refinement of the ecotope to be made.

Dr. Macvicar: I agree that this could well be so. However, I would use ecological differences to indicate the need for defining climate and soil differences rather than to include an ecological component as such in the ecotope.

Dr. Le Roux: I would welcome the general application of the principles described by Dr. Macvicar, especially in the Eastern Transvaal.

Mr. du Toit: I would like to assure Dr. Le Roux that this work will be carried out and that it won't be long before a team gets under way with it in the Eastern Transvaal. I think that Dr. Macvicar's contribution here is the incorporation in one land class of the natural features (that is, climate and soil) that affect crop production, and his account of how land data can be used in crop technology. We would hope that the extension staff, and possibly also farmers, will eventually be able to identify soil series in the field. Finally, it is a little worrying to know, as Dr. Sumner has pointed out, that there are significant soil properties that vary independently of soil series.

Dr. Macvicar: It would seem that the prime function of extension is to interpret for the farmer the demands which land makes on management. It is surely a simple matter for the farmer, using a manual, to apply those practices which must be carried out irrespective of land quality; the main task of extension is presumably not to teach farmers to read. A doctor is not needed to tell us that we must eat and drink or what we should eat and drink. He is needed to tell someone that he has an inflamed appendix; if he does not know that the person has an appendix, that it is inflamed, or how it should be treated, then he is a bad doctor backed by inadequate research. It is essential that an extension officer can identify the properties of land and know—through research—what each ecotope requires for the health of the crop.

Mr. Boyce: In the Natal cane belt moisture is very predominantly the factor limiting cane growth and I would therefore suggest that climate is a much more important criterion than soil.

Dr. Macvicar: I have tried to indicate that potential is a function of climate, soil and management.