# THE USE OF NUMERICAL ANALYSIS TECHNIQUES IN LAND CLASSIFICATION FOR RESOURCES MANAGEMENT: THE CASE OF SOIL SUITABILITY FOR AGRICULTURE

by

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DEDICATION

For my eternity's friend, Sri Chinmoy, who is teaching me to listen, to care, and to grow.

ABSTRACT

A computer model which determines soil suitability for use types, given data on homogeneous soil areas and the pedoecological requirements of use types was designed, implemented, and tested.

The suitability model was called LASTAN. It operates on the assumption that the contribution of any single soil variable to the soil suitability of a land area is not constant but will vary according to the influences of other soil variables present at that site. These variations in contribution are called soil factor interactions. They are incorporated into the model via a series of relatively simple calculations involving matrix transformations. The final output generated by LASTAN is a series of indices signifying the relative soil suitability of each site for the land-use type with which the researcher is concerned. Also included is an indication of which soil factor(s) at each site, if any, are most likely to be strongly limiting for the land-use type being assessed.

To implement the model, the use types that were chosen were groups of agricultural crops which possess a high degree of internal homogeneity with regard to soil requirements for growth. These groups had to be derived from available data on individual

crops. Principal components, Linkage, and Information Analyses were the taxonomic techniques employed. From a set of thirty crops, five groups were created. One of these, the field crops, was selected to be input as data into the soil suitability model.

The homogeneous soil areas chosen were a series of one hundred forty-five map delineations found in SE. Nepean township, Carleton County, Ontario. These delineations were mapped at 1:25,000 by MARSHALL et al, (1979). Most soil variable data (texture, stoniness, slope, drainage, and depth) were taken from this map sheet. The pH, available phosphorus and potassium were measured in the field.

To test the results generated by the model, coefficients of association (correlation) were calculated between LASTAN indices and capability classes on equivalent map delineations. These coefficients suggest the existence of a strong positive relationship between the two systems, and are interpreted as an indication that LASTAN is successful in its purpose.

# RESUME

L'étude porte sur un modèle informatique qui permet le calcul d'indices de potentiel du sol pour différents usages. Au départ, ce modèle prend en compte des unités spatiales pédo-écologiques pré existantes. Dans la thèse, le modèle est développé, puis appliqué à un exemple et, enfin, évalué par rapport à une autre méthode d'estimation du potentiel.

Ce modèle (LASTAN) est fondé sur l'hypothèse suivante: la contribution au potentiel d'une variable pédo-écologique n'est pas constante. Elle varie en fonction des autres variables qui lui sont associées spatialement. Ces interactions sont introduites dans le calcul à l'aide d'une série d'opérations matricielles. Les résultats produits par LASTAN consistent en une série d'indices qui expriment le potentiel des unités spatiales pour chaque utilisation envisagée.

La mise en oeuvre de LASTAN nécessite un choix de types d'utilisations considérés. Le type d'utilisation considéré ici était un groupe de cultures relativement homogène quant aux exigences pédo-écologiques. Ce groupe fut déterminé a la suite d'une procédure de classification numérique portant sur les indications des exigences des cultures individuelles relevées dans la littérature (trois méthodes de taxonomie numérique ont été

utilisées: composantes principales, "linkage analysis" et, analyse d'information). Parmi les cinq groupes formés à la suite de cette procédure, un seul a été choisi pour l'application de LASTAN. Ce groupe contient l'orge, les fèves, le pois, le seigle, le soya et les radis.

Ont été considerées cent quarante cinq unités spatiales pédo-écologiques provenant de la carte des sols de MARSHALL et al, (1979), au 1/25,000. Elles appartiennent à la région du SE de la municipalité de Nepean, Compté de Carleton (Ontario). La plupart des variables pédo-écologiques (texture de surface, pierrosité, pente, drainage de surface, et profondeur) ont été prises sur cette carte. La réaction du sol (pH), les teneurs en phosphore et potasse disponibles ont été mesurées sur des échantillons prélevés sur le térrain.

Afin de vérifier la validité des résultats obtenus par LASTAN, divers coefficients de corrélation furent calculées entre les indices LASTAN et les classes de potentiel agricole (MARSHALL et al - 1979) dans la région d'étude. L'interpretation de ces coefficients démontre l'existence d'une forte relation positive entre les résultats des deux systèmes. La validité du système LASTAN est par conséquent acceptée.

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There are many individuals to whom I owe a considerable debt of gratitude in the preparation of this thesis. Many warm thank you's to my supervisor and mentor, Dr. M. Phipps, Dept. of Geography, Univ. of Ottawa, for his valuable advice, continued interest, ceaseless patience, words of encouragement, and inspiration during all stages of this project. Also, the use of his two computer programs, APCOP and CIPACE greatly facilitated certain aspects of the research.

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# INTRODUCTION

"Oh mother earth, mountain-breasted and ocean-girdled, pardon me for trampling on you." (Ancient Sanscrit Prayer)

## 1.1 OVERVIEW

To the extent that it relates to agricultural land-use, soil may be defined as:

> " ...a three-dimensional body occupying the uppermost part of the earth's crust and having properties differing from the underlying rock material as a result of interactions between climate, living organisms (including human activity), parent material and relief over periods of time and which is distinguished from other 'soils' in terms of differences in external characteristics and/or in terms of gradient, slope-complexity, microtopography, stoniness and rockiness of it's surface", (BRINKMAN & SMYTH, 1973, p.101).

Soil maps are a primary data source to most physical or ecological interpretations of land suitability for agriculture. These documents provide information on basic physical, chemical and morphological soil properties and, when interpreted correctly, may be used to predict the performance characteristics of a landscape under one or a variety of different land-use types, (STEELE, 1967, p.1).

In the past, some criticism has been made concerning the ability of mapped soil types to predict the agricultural potential of land, (BUTLER, 1964, p.233; GIBBONS, 1961, p.98-99). The principal argument of these authors has been that a specific soil type was not sufficiently homogeneous with respect to factors affecting productivity to allow reliable interpretations to be made. However, the advent of modern soil mapping, which recognizes soils as ecological components of landscapes, (DUMANSKI et al, 1972, p.29-30; HILLS et al, 1970, p.44-47), in addition to the use of larger mapping scales and increased survey intensity, has gone far towards overcoming this problem.

The purpose of this thesis is to design and make operational a methodology with which these "second generation" (van den BROEK, 1978, pers. comm.) soil maps may be interpreted quickly, accurately, and at low cost. Although this author's principal interest is with agriculture, the basic framework created is deemed applicable to non-agricultural land-use types as well. As demonstrated in Chapters 3 and 4, below, this framework is apt because of the holistic and interactive manner with which it assesses the relevant soil/landscape factors contained in each outlined unit. These units or delineations are defined on maps by means of:

> " ...a collection of symbols representing discrete soil/land elements. Because each delineation is 'homogeneous' with respect to its characteristics, each is a discrete, scientifically sound, pedoecological area that can be reinterpreted at will for a multitude of uses", (MARSHALL et al, 1979, p.41)

Soil suitability classifications are one of several types of interpretations that can be made from soil maps. Soil suitability has been defined as:

> "...the physical [fitness] of soil and climate for production of a specific crop or group or sequence of crops, or for other defined uses or benefits, within a specified socio-economic context but not considering economic factors specific to areas of land", (VINK, 1975, p.249).

This thesis will concern itself exclusively with actual soil suitability or "internal actual land suitability", (VINK, 1975, p.249). This concept is very similar to that of "capability", (BRINKMAN & SMYTH, 1973, p.101), as defined and described by the C.L.I. (1972, p.3), and KLINGEBIEL & MONTGOMERY, (1961, p.1). Here soils are assessed according to specific management assumptions which do not encompass major land improvement practices lying beyond the means of the average farm operator[1].

Recent heavy, irreversible losses of prime agricultural land to urban uses in Canada (GIERMAN, 1977, p.28-31), coupled with a growing global environmental conciousness, has resulted in the recognition that rational land planning is necessary at all scales and levels of jurisdiction. This need has created an increased demand for detailed soil maps for interpretive purposes. It is hoped that this thesis will contribute to that theoretical and pragmatic base which soil surveyors and land planners use in their interpretations of these maps.

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[1]An interesting discussion of these different kinds of productivity ratings and soil potentials, especially as they relate to current and potential conditions, different levels of management, and varying socio-economic conditions may be found in MACVICAR, (1974, p.1-4).

## 1.2 THE PROBLEM

Two key elements in any interpretation of soil capability or suitability are the selection of soil characteristics relevant to the use(s) considered, and the methodology employed to weigh or rate these characteristics in order to arrive at a predictive performance class or index. Of the latter, several types have been proposed in the literature.

### 1.2.1 Capability Classification Systems

As mentioned above, the results of capability classifications are equatable with those of actual soil suitability. Although the particular land-use types, project scales, and class categories may differ from study to study, what is of interest here is the way in which capability classes, subclasses, and in the U.S.A., capability units, are determined.

According to MILLER, (1978, pers. comm.) and HOFFMAN, (1977, pers. comm.), the assessment of soil capability requires a considerable amount of experience in pedology as well as knowledge of crop science and agrometeorology. Essentially it is this expertise which allows the soil survey interpreter to synthesize or integrate field conditions and crop requirements, weighing the positive or negative effects of each soil characteristic in isolation and in combination with other soil factors, to arrive at a capability rating. These ratings are relative as well as qualitative. Thus the meaning of a Class 1 soil, for example, will vary somewhat from region to region depending both upon the characteristics of the two areas and the individual scientists who conducted the interpretation, (DUMANSKI, 1978, pers. comm.).

Studies made by ANDERSON, (1971); HOFFMAN, (1973); and PATTERSON & MACKINTOSH, (1976), in southern Ontario, have demonstrated that the C.L.I. (Canada Land Inventory) capability classes are related to crop yields and economic returns of standard field crops. In addition, GOODCHILD, (1976), working in Manitoba, found that areas of a single capability class are relatively homogeneous with respect to selected physical parameters.

One drawback to the capability system is that while the data bases are compiled and mapped with painstaking scientific rigor, the way in which interpretations are carried out relies more upon a "feel for the land" than a clear, scientific, easily replicable methodological framework. According to BRINKMAN & SMYTH, (1973, p.27), the former is often insufficient for sound land evaluation.

Other limitations of the C.L.I. have been outlined by NOWLAND, (1977, p.11); and PATTERSON, (1978, p.1).

### 1.2.2 Analogue Systems

Described in detail by ANDERSON, (1971, p.9-10); HOFFMAN, (1971, p.10-11); and NIX, (1968, p.78-79), many researchers have attempted to determine soil productivity using concepts based on transfer by analogy. Here, observations of yields versus inputs at specific soil test sites are extrapolated to other areas defined by supposedly identical soil types.

Reviews of these systems, based on "first generation" soil mapping concepts, by AVERY, (1962, p.342-43); BUTLER, (1964, p.233-34); and GIBBONS, (1961, p.98-100) have been somewhat critical. The principal argument of these authors is that soil types usually correlate poorly with yield. RUST & ODELL, (1957, p.174), estimate that between 50 and 150 test sites should be examined over at least 10 years before accurate yield estimates can be made. Clearly, the time and size of test areas needed to estimate yield per crop restricts the applicability of these systems. In addition no accounting for the effects of specific soil properties upon soil suitability and plant growth is made by analogue systems.

### 1.2.3 Site Factor Methods

Similar to "semi-quantitative" approaches described by VINK, (1975, p.304), "site factor" methods of soil evaluation, (NIX, 1968, p.79-80), have been strongly advocated by researchers in Southern Ontario, particularly ANDERSON, (1971); HOFFMAN, (1973); MACDONALD, (1972); and VAN VLIET, (1974). Other researchers including AVERY, (1962); BUTLER, (1964); ODELL, (1958); RUST & ODELL, (1957); and VISSER, (1950), have also employed this technique to assess soil quality for agricultural purposes.

Basically, site factor methods attempt to relate certain measured soil properties (independant variables) to known crop yields (dependant variable) in a multiple regression equation. This equation is then used to define the relationship between soil factors and productivity. Performance classes are devised which pay "heed to the responsible factors and their relationship with yield", (HOFFMAN, 1971, p.11).

The principal drawbacks associated with this approach are elucidated by BUTLER, (1964, p.235-36). First, such studies are empirical and cannot truly identify causes of yield variation. Second, investigations of this type can be carried out only in areas <u>already</u> established in agriculture, and therefore are of little use to researchers interested in virgin "development" areas unless transfers by analogy are envisaged. Third, the technique is, in essence, a statistical survey. The lack of an experimental element precludes the "opportunity to sort out all interactions".

In addition, this author's review of the literature reveals that established R squared values rarely exceed +0.56, (RUST & ODELL, 1957, p.173), or that regression equations derived are too complex for realistic use in productivity studies, (ANDERSON, 1971, p.35). Thus the ability of the system to effectively predict yield is mediocre at best, especially when compared to the correlation coefficients of capability classification systems with yield obtained by ANDERSON, (1971); HOFFMAN, (1973); and PATTERSON, (1978).

### 1.2.4 Parametric Models

Parametric techniques, defined and reviewed by RIQUIER, (1974, p.47), are purported to:

1. evaluate separately the different properties of soils giving them separate numerical valuations according to their importance within and between each other.

2. combine these factor values according to a mathematical law which accounts both for the relationships and interactions between factors to produce a performance index.

3. rank the soils according to their index values for the use(s) under consideration.

Although several variants of the parametric approach have been suggested, the one receiving most attention has been a multiplicative system. The Storie Index, (STORIE, 1950, 1976) is perhaps the best known of these in North America. Other authors such as FRANKART et al (1970); RIQUIER et al, (1970); VINK, (1960); and in Canada, MILLETTE & SEARL, (1969); and SEARL, (1966), have also used a multiplicative approach.

Here soil properties are rated with values ranging between 0 and +1. These values are then input into an equation similar to that shown in 1.2.4. The result, "IA", also takes values ranging between 0 and +1 and is controlled essentially by the most limiting factor.

1.2.4 IA = W x D x C x N x M x R x P ...

where IA = an index of production
W,D,C etc. = soil factor values

Source: MILLETTE & SEARL, (1969, p.3).

RIQUIER, (1974, p.51), examines the advantages and disadvantages of parametric systems. Principal advantages are that these systems examine individual soil factors, can be modified for specific crops or crop groups, are supposedly quantitative, and are particularly adapted to computer applications with large data banks.

The main disadvantage is that the evaluation of standard factor values is somewhat subjective. Another problem not described by RIQUIER is that only negative interactions between factors are accounted for. Furthermore, even this accounting is inflexible. It makes no selection as to exactly which factors should be involved and to what degree they should be involved in the interaction. Thus, for example, low nutrient levels have the equivalent negative effect on all other factors as, say, severe topography. Clearly, this situation is not representative of reality under assumptions of even the most basic management practices.

Also, positive interactions are neglected. Thus the synergistic effects on crop production of two factors existing together at an optimum are not recognized. Such interactions, examined and documented by STEELE, (1967, p.5); RUSSELL, (1973 p.61-67); and DANIELSON, (1972), are seen as significant to any study of soil suitability.

MILLETTE & SEARL, (1969); SEARL, (1966); and RIQUIER et al, (1970) have suggested a way of partially eliminating the problem of inflexible negative interactions discussed just above. No system, to this author's knowledge, has yet to recognize and account for positive interactions.

### 1.2.5 Design Criteria and Orientation of this Thesis

The methodological approach proposed in this thesis attempts to resolve some of the key problems found in the four techniques described above. It is more systematic, and thus more easily reproduced, than capability classifications. It is quicker to implement than the analogue approach. It is not restricted to areas actually under agriculture, as is the site factor method. In addition, it is less statistical than the analogue and site factor methods, and more an examination of the causes and effects of soil properties upon suitability. Finally, it is more flexible in its treatment of interactions than traditional parametric approaches. Its characteristics resemble those of the "integrated" approach, (MABBUTT, 1968, p.16-17), but also include broad systematic features of the parametric models.

Its principal design criteria are that:

1. the results generated by it must conform to the definition of "soil suitability" (see Section 1.1, above) in terms of a flexibility to adapt to different land-use types as well as to different sites on a multitude of scales under different project objectives. In this study, for example, the land-use types chosen were crop groups, (see discussion in Chapter 2), and the operating scale was 1:25,000. However, the system is seen to be equally well adapted to assessing soil suitability for individual crops or, alternatively, for more general land-use types such as "general" agriculture in addition to non-agricultural land-uses.

2. it should systematically recognize and flexibly account for both positive (synergistic) and negative (limiting) interactions in addition to the soil requirements of each land-use type between soil factors.

3. it be succinct, suggest quantification, and be easily reproduceable in a comprehensible, scientific fashion which is conducive to computer programming.

The integrated-parametric type model developed here is then put into operation on a specific test study area, under a predetermined land-use and soil factors following defined assumptions and using suggestions made by VINK, (1975, p.248-249) concerning "actual internal qualitative soil suitability".

A test of the results in Chapter 4 provides a crude evaluation of the success of the model.

1.2.6 Assumptions

Of paramount importance in understanding and assessing the significance of results are the assumptions incorporated into the soil suitability model. These are outlined below.

First, any modern agricultural cropping system needs certain human inputs in the form of managament practices before a soil will produce. These activities, in combination with inherent land qualities, determine the ultimate productivity of a soil, (STEELE, 1967, p.5; SOIL SURVEY STAFF, 1962, p.367; HILLS et al, 1970, p.21). It may be argued that, given sufficiently intense soil management and agricultural technology, one can completely eliminate the importance of land qualities for agriculture. However, this thesis takes a more conservative viewpoint and examines productivity from the perspective given by PAPADAKIS, (1975, p.10-19), and WALSH & GARDINER, (1976, p.8). These authors stipulate that it is in a farmer's best interest to take advantage wherever possible of favorable site conditions in order to reduce input costs.

Here, an average level of management is assumed which includes timely tillage, fertilization, liming and weed control in addition to crop rotations to maintain favorable soil structure and nutrient levels.

Second, the feasibility of major improvement practices, including levelling, tile drainage, and irrigation, is not considered or incorporated.

Third, the suitability assessment is based upon soil survey data provided by MARSHALL et al, (1979) and field sampling where necessary. Crop soil requirements are derived from the literature.

Fourth, social, economic, and cultural factors are not considered, These include location, intensity of land-use, transportation facilities, etc. Also ignored are variations due to temperament, talent, and motivation of the individual farm operator as well as the socio-economic effects of incorporating the crop group assessed in this study into the regional economic environment of the study area.

Fifth, climate is assumed not to vary significantly across the study area.

In keeping with the nature of these assumptions it is emphasized that "soil suitability assessment" and "land evaluation" are two different concepts. The former is concerned with determining a degree of <u>ecological</u> <u>feasibility</u> or physical potential. It is a means of indicating how specific uses can be expected to perform in different areas given data on climate and soils within a specified set of management conditions. Because of its assumptions soil suitability is essentially a static concept, restricted to one point in time. Land evaluation, on the other hand, defines the land-use patterns required to arrive at a set of predetermined objectives. These objectives are governed by human values, economics, ecology and time. It is a dynamic "system which indicates [expresses] the relative worth or utility of allocating a particular use, as opposed to all others considered, to an area", (CENTRE FOR RESOURCES DEVELOPMENT, 1977, p.3), assuming specified objectives. Thus, soil suitability is only a part, albeit an important part, of land evaluation.

## 1.3 STUDY AREA

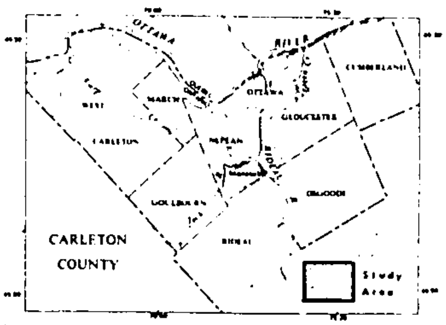
### 1.3.1 Location

The study zone, within which the soil suitability methodology was made operational, is a portion of southeast Nepean Township in Carleton County, Ontario. It comprises a square shaped surface of some 7050 hectares bounded on the east and west by the Rideau River and Moodie Drive respectively and on the north and south by Fallowfield Road and Regional Road 8. Regional Road 8 forms the Nepean-North Gower Township boundary. The Jock River, an east-west tributary of the Rideau River, bisects the study region into two roughly equal portions, (see Figure 1).

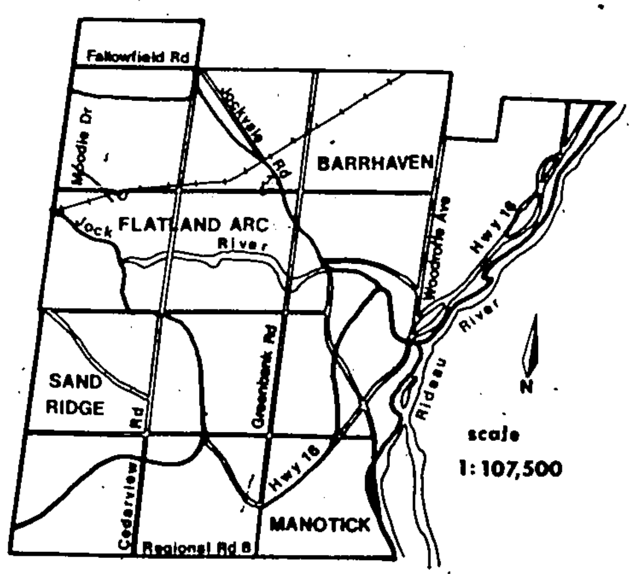
### 1.3.2 Reasons for Choice

There are four major reasons why this area was chosen. First, it was easily accessible to the author by an abundance of main highways and secondary roads which crisscross the territory.

**Figure 1: Location Maps of Study Area**




Source: SOIL RESEARCH INSTITUTE, (1976)




scale
1: 107,500

Source: HUFFMAN & DUMANSKI, (1978)

Thus, field checks were made possible with few logistical problems.

Second, it is a predominantly rural zone which has recently undergone somewhat rapid land-use changes. Agriculture in much of this area is currently being threatened to the north, east, and west by urban and industrial sprawl. It forms, therefore, a demographically and socio-economically representative part of Nepean-Gloucester which, between 1964 and 1973 lost some 5133 hectares of land to urban uses. Some 45 per cent of this loss was prime agricultural land (capability classes 1, 2, and 3), (GIERMAN, 1976, p.26-28).

Third, a detailed soils map of the area at 1:25,000 by MARSHALL et al (1979), and described by DUMANSKI et al, (1978, p.33-42), was available as a prime data source. In addition, maps of land-use and soil capability for field crops at the same scale complemented this sheet.

Most important, however, was that the study zone possesses a wide range of pedoecological conditions within a relatively small area. This natural diversity made it an ideal pilot area in which to test the methodology developed here.

### 1.3.3 Soils

Several kinds of soil are represented in southeast Nepean. These bodies may be identified and described by the soil taxonomic groups as defined by the Canadian Soil Survey Committee, (C.S.S.C., 1978). Table 1 shows the 4 Orders, 6 Great Groups, 10 Subgroups, and 30 Series present. In the field MARSHALL et al, (1979), mapped these soils into 19 different soil Associations, 46 soil Landscape Units and 145 Map Delineations[2].

### 1.3.4 Climate

Nepean Township is characterized by a relatively humid, cool, continental climate with warm summers and severe winters. Air temperatures range from a mean daily minimum of -15.6 in January to a mean daily maximum of 26.6 degrees Celsius in July at Ottawa International Airport. The mean annual temperature of the area is +5.8. There are approximately 162 consecutive frost-free days per growing season, (ATMOSPHERIC ENVIRONMENT SERVICE, 1973, p.179).

The mean total precipitation of the area is 850 millimeters of which 57 per cent falls as rain between May and September, (ATMOS. ENVIR. SERV., 1975, p.18,43,68).

Soil climate in Nepean has been classified as humid, mild, and mesic. This infers that soils are never dry longer than 90 consecutive days in most years and that the annual soil temperature regime ranges from between 15 to 22 degrees Celsius, (CLAYTON et al, 1977, p.73-80; MARSHALL et al, 1979, p.12).

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[2]See MARSHALL et al (1979, p.40-47) and DUMANSKI et al, (1972, p.27-30) for definitions and explanations of these mapping concepts and their relationship to soil taxa.

TABLE 1

Soils of southeast Nepean Township

| ORDER | GREAT GROUP | *SUBGROUP | SERIES |
|---|---|---|---|
| Brunisol | Melanic | Gleyed | Achigan<br>Castor<br>Dalhousie<br>Franktown<br>Piperville<br>Rideau |
| | | Gleyed Eluviated | Matilda |
| | | Eluviated | Chateauguay<br>Grenville<br>Kars<br>Queensway |
| | | Orthic | Farmington<br>Oka<br>Nepean |
| | Sombric | Gleyed | Mountain<br>Ramsayville |
| | | Orthic | Carlsbad<br>Mille Isle |
| Gleysol | Humic | Orthic | Allendale<br>Bainsville<br>Brandon<br>Carsonby<br>Lyons<br>North Gower<br>Ste. Rosalie<br>St. Samuel<br>Vaudreuil |
| | Rego | | Borthwick |
| Luvisol | Gleyed | Grey Brown | Carp |
| Organic | Humisol | Terric<br>Terric Mesic | (unnamed)<br>" |

The number of degree days (+5 degrees Celsius base) ranges between 1720 and 2220. The mean thermal period[3] is 120 days.

### 1.3.5 Present Land Use

The most intensive agricultural land-use in the study area occurs on the flat crescent formed by the Rideau and Jock River plains. In Figure 1 this sector is delineated as Flatland Arc and Manotick. Here one finds a predominance of viable dairy and mixed farms interspersed with smaller areas of abandoned land and residential homes. Non-agricultural land in this sector is most concentrated along Highway 16 and the Rideau River in the sector called Manotick.

West of the Jock River plains, in the sector called Sand Ridge in Figure 1, lie predominantly light-textured sands and sandy-loams. Much of the northern section of this ridge has been taken over by industrial pit operators, construction firms, Nepean's municipal dump, and several reforestation plots. Intermingled are patches of relic pasture and hay fields. To the south, agricultural land-use has a stronger hold, much of the area being in pasture, hay, small grains, soybeans and, occasionally, corn.

Northeast of the Jock and Rideau River crescent is an area called Barrhaven in Figure 1. Here one finds a large expanse (1214 hectares in 1975) of pasture, hay and recently-abandoned land interspersed with areas under corn and small grains.

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[3]Thermal period = Number of days soil temperature to 50 cm. depth is greater than +15 degrees C.

Although this sector, especially between Woodroffe Avenue and Cedarview Road, contains large portions of capability class 1 and 2 land, farming is fragmented due primarily to urban expansion, sewer and road construction, as well as topsoil removal.

To the east, between Fallowfield Road and the Jock River, the situation is much the same. Hearts Desire subdivision on the Jock River between Jockvale Road and Highway 16 is the main agent of urban growth amidst these fertile clays.

The amount of abandoned agricultural land in the study area is a strong indication of a changing land-use. Privately owned farms are slowly being squeezed out of existence by commercial real estate companies, industrial materials extractors, municipal installations and speculators.

# Chapter II

## CROP GROUPING

"...learn the temper and quality of our ground, the depth and substance of our soil and the colour of our ground and then to consult carefully what plants are natural to such a soil and which plant will grow most freely upon it. For if we do not take care to adapt our plants to our soil we must not hope for any tolerable success." (VIRGIL, 100 B.C., from HOFFMAN, 1971, p.4)

### 2.1 OVERVIEW

Integrated-parametric type approaches to soil suitability require, among other things, two kinds of information. On the one hand, the researcher must have access to a soils data base of sufficient detail to allow interpretations to be made at the scale he wishes to operate. In this thesis most of that information was readily available from recent work by MARSHALL et al, (1979). On the other hand, the researcher must also possess data on the land or soil use types with which he is concerned. Soil and climatic requirements, response to specified management practices, and, soil property interactions all contribute to this second body of data. Furthermore, this information and the land-use types to which it relates must exist in or be transformed to a form compatible with the scale and objectives of the study.

In this thesis it was decided to create a scenario in which soils could be rated for groups of agricultural crops. Crop _groups_ as opposed to _individual_ crops were chosen as the land-use type for two reasons. First, the masses of data to assess and manipulate coupled with the high degree of duplication which would undoubtedly result from calculating the soil suitability for single agricultural crops would be unwieldy. Second, the agricultural planner's work would be significantly reduced if, when attempting to plan land-use, only four or five[4] indices of suitability needed to be compared instead of twenty or thirty[5]. However, data concerning soil and climatic requirements and soil factor interactions for _groups_ of crops was not readily available. It had to be derived from information contained in the literature concerning _individual_ crops.

This chapter describes the processes and techniques which were employed to obtain crop groups which possess both a relatively high degree of internal homogeneity and, at the same time, remain externally distinct from one another with respect to soil requirements for optimum growth.

Because these groups were derived for a special purpose to deal with a specific problem they constitute elements of an _arti-_

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[4]Each index in this case would represent the suitability of an aerial unit for a group of similarly behaving crops.

[5]Here one would be dealing with an index of suitability for each single crop.

ficial or interpretive, as opposed to a natural, classification system, (HARVEY, 1971, p.329; SIMONSON, 1971, p.3).

### 2.1.1 Crops Chosen

The choice of crops to be grouped was based upon two criteria.

First, and most important, they were limited to those grains, legumes, fruits, and vegetables which are, apriori, climatically suited to the area. Principal data sources on crop climatic requirements were ALI-KHAN & ZIMMER, (1976); BRADT ET AL, (1975, 1977); CHONG, (1975 a,b); COLIN, (1975); CRAIG, (1975, 1976); DONOVAN ET AL, (1974); HALL ET AL, (1975); NONNECKI, (1975); O.M.A.F., (1978 a,b); OUELLET, (1975); READ, (1977); RIEKELS ET AL, (1976); and ROWBERRY ET AL, (1976). Consultations with agricultural representatives at O.M.A.F. (Ontario Ministry of Agriculture and Food), Carleton County office, and crop specialists at Kemptville College of Agricultural Technology, Ontario filled any gaps in the literature.

Crop climatic requirements were then compared with the climatic conditions of the Ottawa area. Data examined were air temperatures (mean daily, mean daily maximum, mean daily minimum), spring and fall probabilities of frost occurrence, frost free periods, cumulative heat units over the growing season, hours of daylight over the growing season, soil temperatures to 100 cm. depth, and precipitation during the growing season. This data came from the following sources: EDEY ET AL, (1968, 1977);

ATMOS. ENVIR. SERV., (1973, 1975); HOLMES & ROBERTSON, (1966); MARSHALL ET AL, (1979); N.R.C., (1978); and OUELLET ET AL, (1975). Much of it has been summarized in Chapter 1. By meeting this climatic criterion it was felt that the only other natural factor affecting a crop's chances of flourishing in the area (other than "acts of God", human input, and diseases unrelated to soil) would be soil conditions themselves.

The second condition of acceptance for a crop was that data had to be available which specified how this crop responded to varying soil and climatic conditions.

Using these criteria as guidelines the following crops, shown in Table 2, were chosen for grouping.

TABLE 2

Crops chosen

| NO | CROP | CODE | SELECTED ACCEPTABLE VARIETIES |
|---|---|---|---|
| 1 | Asparagus | ASP | Viking |
| 2 | Beet | BEE | Little Egypt |
| | | | A Egypt Select |
| | | | A Early Redball |
| | | | Detroit Dark Red |
| | | | Burpees Golden |
| 3 | Broccoli | BRO | Italian Sprouting |
| | | | Green Mountain |
| | | | Walthan 29 |
| | | | Spartan Early |
| 4 | Brussels Sprouts | BRS | Jade Cross |
| | | | Jade Cross E |
| 5 | Cabbage | CAB | Evergreen Ballhead |
| | | | Storage Green |
| | | | Early Marvel |
| | | | Viking Extra Early |
| 6 | Carrot | CAR | Gold Pak |
| | | | Imperator |
| | | | Danvers |
| | | | Spartan |
| | | | Nantes |
| | | | Pioneer |
| 7 | Cauliflower | CAU | Extra Early Snowball |
| | | | Idol Original |
| | | | Dominant |
| | | | Clou |
| 8 | Celery | CEL | Florida |
| | | | Nonbolting Green |
| | | | Utah |
| 9 | Corn | COR | Northern Vee |
| | | | Garden Treat |
| | | | Tasty Vee |
| | | | Blitz |
| 10 | Cucumber | CUC | Tablegreen |
| | | | Marketmore 70 |
| | | | Shamrock |
| | | | Gemini |
| 11 | Pea | PEA | Thomas Laxton |
| | | | Green Arrow |
| | | | Lincoln |
| 12 | Peppers | PEP | Early Hybrid (Stokes) |
| | | | Early Canada Bell |
| | | | Stadons Select |
| 13 | Lettuce | LET | Fulton |
| | | | Evergreen M-1 |

| | | | |
|---|---|---|---|
| | | | Ithaca M-1 |
| | | | Black-seeded Simpson |
| 14 | Onion | ONI | Stokes Importer |
| | | | Canada Maple |
| | | | Superspice |
| | | | Storage King |
| 15 | Parsnips | PAR | Hollow Crown Improved |
| | | | Harris Model |
| 16 | Potato | POT | Onaway |
| | | | Superior |
| | | | Norchip |
| | | | Chieftan |
| | | | Kennebec |
| | | | Belleisle |
| 17 | Radish | RAD | (all varieties accepted) |
| 18 | Snap Beans | BNS | Contender |
| | | | Spartan Arrow |
| | | | Improved Tendergreen |
| | | | Harvester |
| 20 | Spinach | SPI | Melody |
| | | | America |
| | | | Cold-rest Savoy |
| | | | Dark Green |
| | | | Longstanding Bloomingdale |
| 20 | Squash | SQU | (all varieties accepted) |
| 21 | Tomato | TOM | New Yorker |
| | | | Springset |
| | | | Veebright |
| | | | Moira |
| | | | Quinte |
| | | | Veepick |
| | | | H1350 |
| 22 | Turnip | TUR | Purple Top Whiteglobe |
| | | | York |
| | | | Laurentian |
| | | | Shogoin |
| 23 | Apple | APL | Delicious |
| | | | Jonathan |
| | | | Yellow Transparent |
| | | | McIntosh |
| | | | Cortland |
| 24 | Blueberry | BLB | Berkley |
| | | | Blueray |
| 25 | Raspberry | RAS | Heritage |
| | | | Creston |
| | | | Comet |
| 26 | Strawberry | STB | Veestar |
| | | | Redcoat |
| | | | Earlidawn |
| | | | Vibrant |
| | | | Midway |

| | | | |
|---|---|---|---|
| 27 | Barley | BAR | Herta<br>Bruce<br>Pequis<br>Perth<br>Trent<br>Vanier |
| 28 | Oats | OAT | Elgin<br>Garry<br>Oxford<br>Scott |
| 29 | Rye | RYE | (most varieties accepted) |
| 30 | Soy | SOY | Maple Arrow |

## 2.2 COMPONENT PARTS OF GROUPING PROCEDURE

The grouping procedures used here followed, in general, the traditional approach taken by numerical taxonomists concerned with classifying a population of individuals (in this case, crops) with respect to a series of defined attributes (soil conditions for optimum growth). Several excellent reviews of these techniques exist in the literature by DALE & ANDERSON, (1972); SOKAL & SNEATH, (1963); SPENCE & TAYLOR, (1970); WILLIAMS & DALE, (1965); WILLIAMS, LAMBERT & LANCE, (1966); and YEATES, (1974). It is mainly from these sources that the mathematical methods employed here were chosen.

### 2.2.1 The Data Matrix

With the set of crops already chosen, the next step in the grouping process was to choose variables or attributes with which to describe these crops. Each soil variable met the following conditions:

1. it was important to the growth of the crops chosen;

2. values associated with it varied significantly over the group of crops;

3. data concerning the response of all crops in the population to changes in the value of this variable were readily available in the literature.

On the basis of these criteria eight soil variables were chosen. They are: Soil reaction (SPH), soil texture (TEX), available nitrogen (NNN), available potassium (KKK), available phosphorus (PPP), optimum rooting depth (ORD), soil water availability (WCN), and soil drainage requirements (ODR).

Several other soil variables were originally considered for inclusion as well but were subsequently rejected for various reasons.

Stoniness, topography, and soil structure, for example, all play significant roles in determining crop growth. However, the response of most crops to variations in these variables is relatively uniform and hence unsuited as input in the calculation of the similarity coefficients described below. Their inclusion in the data matrix would inflate these coefficients and thus jeopardize the accuracy of the crop groups.

Optimum organic matter content and carbonate content requirements were omitted because of a lack of data. Tolerance to soil salinity is another important variable for which data is both available and which varies, in some cases significantly, between individual crops. It was neglected in this thesis because the study area contains no soils adversely affected by soluble salts, (MARSHALL ET AL, 1979, p.118-121).

Each variable was divided into a series of classes designed to: a) accommodate both euryecious and stenoecious differences in crop requirements, (KNIGHT, 1965, p.18-19), b) cut down on potentially ambiguous correlation coefficients and, c) match the level of accuracy given by the available data.

The data sources used to describe each crop were many. Major inputs include BLAND, (1971); HUGHES & METCALFE, (1972); KNOTT, (1957); LEONARD & MARTIN, (1963); NIEUWHOFF, (1969); O.M.A.F., (1978 a,b); PARKS, (1955); RODALE, (1976, 1977); SALTER & GOODE, (1967); THOMSON & KELLY, (1957); WARE & McCOLLUM, (1975); WEAVER & BRUNER, (1927); WEAVER, (1926); and WORK & CAREW, (1955).

A binary matrix was constructed. The rows represent individual crops. The columns are the individual states of the variable used to describe the crops. Zeros (0) represent sub-optimal conditions whereas ones (1) imply optimal conditions for the crop in question. The matrix has thirty rows (individual crops) and thirty-nine columns (classes of soil variables). Portions of it are reproduced in Table 3 below, and in Tables 12 to 17 of Appendix E.

TABLE 3

The first five rows & twenty columns of the data matrix plus a description of variable classes

| | SPH | | | | | | TEX | | | | | | NNN | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 |
| ASP | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| BEE | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| BRO | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| BRS | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| CAB | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

| VARIABLE | CLASS | DESCRIPTION | |
|---|---|---|---|
| SPH | 1 | very strongly acid | <5.0 |
| | 2 | strongly acid | 5.0-5.4 |
| | 3 | moderately acid | 5.5-5.9 |
| | 4 | slightly acid | 6.0-6.7 |
| | 5 | neutral | 6.8-7.2 |
| | 6 | slightly alkaline | >7.2 |
| TEX | 1 | fine sand | |
| | 2 | sandy-loam | |
| | 3 | loam | |
| | 4 | clay-loam | |
| | 5 | clay | |
| | 6 | muck | |
| NNN | 1 | very low | 0-26 (kg/ha |
| | 2 | low | 27-53 available) |
| | 3 | moderate | 54-80 |
| | 4 | high | 81-107 |
| | 5 | very high | 108-134 |

### 2.2.2 The Grouping Algorithms

According to WILLIAMS, LAMBERT & LANCE, (1966, p.247), "problems of numerical taxonomy allow for a choice in the overall type of classification [that can] be adopted, namely between hierarchical and non-hierarchical (ie. reticulate) systems". The difference between these two types is that hierarchical (agggolomerative) methods attempt to subdivide a population according to a progression of its most efficient steps whereas non-hierarchical grouping methods attempt to define the most efficient or homogeneous groups without regard to the 'route' by which they are obtained. In their introduction, WILLIAMS, LAMBERT & LANCE, (1966, p.247) state that:

> "...since no method is yet available which simultaneously maximizes hierarchical efficiency and group homogeneity, the user must decide whether to optimize the groupings or the route".

Because of the ultimate limitations of any grouping technique, three independant methods were chosen to help define workable, logical crop groups based on edaphic properties. They were principal componants, linkage, and information analysis. Figure 2, below, shows the flow of information and decision-making used here, and the role of these analyses within this process.

#### 2.2.2.1 Matrices of Interconnection

Of these three methods, principal components and linkage analysis operate from the same $\Phi$ similarity matrix. Information analysis uses a matrix of information statistics. It was hoped that the use of two independant interconnection matrices would further aid in obtaining both mathematically and edaphically logical groups without fear of internal or external bias.

The 30[$\Phi$]30 correlation matrix was composed of coefficients of correlation between each pair of crops. Described by KEITH, (1972, p.67) and SOKAL & SNEATH, (1963, p.134-135), $\Phi$ was designed for nominal data and takes a value of +1 under conditions of perfect similarity, 0 where no pairwise relationship exists, and -1 in cases of perfect dissimilarity or negative correlation. See equation 2.2.2.

For any two individuals defined by 'n' variable states:

2.2.2 $$\Phi = \frac{(A \times D) - (B \times C)}{\sqrt{(A+B) \cdot (C+D) \cdot (A+C) \cdot (B+D)}}$$

where:

A= number of variable states for which both individuals X & Y have positive (1) entries.

B= number of variable states for which individual X has a positive (1) and individual Y has a negative (0) entry.

C= number of variable states for which individual X has a negative (0) and individual Y has a positive (1) entry.

D= number of variable states for which both individuals X & Y have negative (0) entries.

N= A+B+C+D

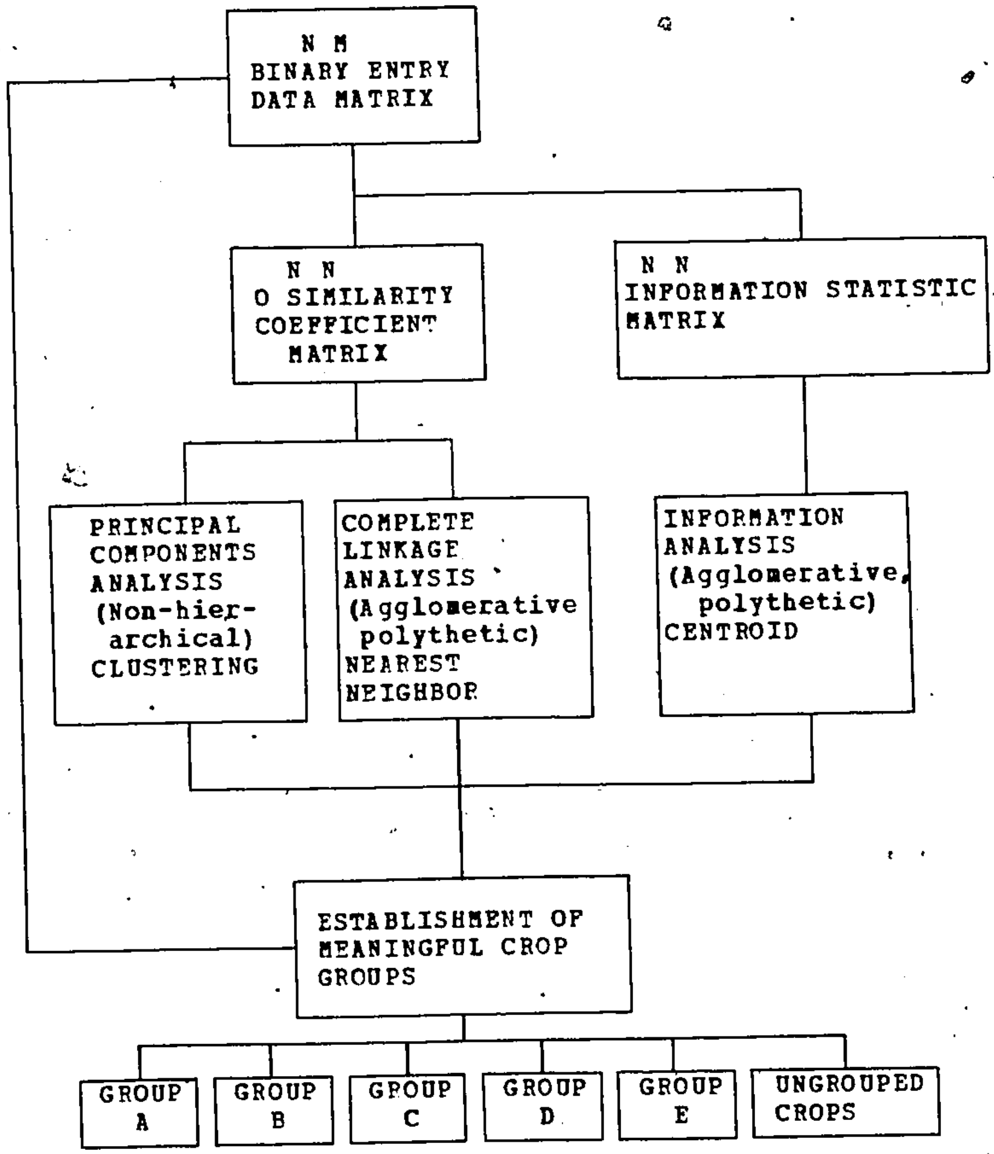


Figure 2: Box diagram showing the flow of information employed by the author in crop grouping procedure

The second matrix of interconnections employed in the crop grouping procedure took the same dimensions as the first. Its entries, however, were information statistics. In this study pairs of crops are examined. Disorder, or $\Delta I$, is a measure of the degree to which these crop pairs possess dissimilar optimum growth requirements with regard to the soil variables used to define them.

$\Delta I$ is calculated using the formula outlined in DALE & ANDERSON, (1972, p.640) where for every pair of crops 'i' and 'k' defined by variable state 'j' out of a total of 'm' states:

2.2.3 $$\Delta I_j = [I(ik,j) - I(i,j) - I(k,j)]$$

and

$$\Delta I = \sum_{j=1}^{m} \Delta I_j$$

where

I(ik,j)= the total information contained in both crops at variable state 'j'.

I(i,j)= the total information contained in crop 'i' at variable state 'j'.

I(i,k)= the total information contained in crop 'k' at variable state 'j'.

Large values of $\Delta I$ indicate that the joining of two crops to form one group can only be made by sacrificing a large amount of information. Thus, the crops are relatively dissimilar. Conversely, if two crops have nearly identical soil requirements for growth then the amount of information lost by fusing them into one group will be very small.

2.2.2.2 Principal Components Analysis (P.C.A.)

P.C.A. is a non-hierarchical taxonomic technique. When used in problems of classification or grouping it searches to create and maintain group efficiency irrespective of the route by which these groups are obtained. First developed by HOTELLING, (1933), its operational characteristics have been well described elsewhere by CATTELL, (1965); DURAN & ODELL, (1974); RUMMEL, (1967); YEATES, (1974), and numerous others. GOODALL, (1954), provides an excellent review of its use in vegetation studies, and PHIPPS, (1968 a,b,c), demonstrates its applicability to land-use analysis.

Here Q-mode P.C.A. (as opposed to R-mode) was employed because the objective was "to discern patterns of individuals [crops]", (RUMMELL, 1967, p.446), rather than patterns of variables. The factors which are ultimately created represent combinations of the eight soil property variables. The loadings on each factor reveal the extent to which each crop is influenced by changes in that factor.

Following recommendations made by KING, (1969, p.174), and YEATES, (1974, p.221), factors which explained less than five percent of the total variation in the set of crops were ignored.

Implementing this convention left five relevant factors which are interpreted in Appendix D.

A tentative grouping of crops was made by examining each relevant factor graph. Those groups of points (crops) most tightly clustered (internally homogeneous with respect to each factor graph) and autonomous with respect to other clusters (externally heterogeneous or unique) were taken to be the logical groups derived by the analysis. Factor loadings, factor eigen values, percent explanation of total variation by each factor, and cumulative percentage explanation are shown in Table 4.

2.2.2.3 Linkage Analysis

This grouping procedure was implemented both as a reliability test on the groups formed by P.C.A. and as an aid to better understanding the hierarchical structure involved in crop group formation. It is an agglomerative, polythetic, hierarchical classification tool which uses, as input, the same similarity matrix as P.C.A., (WILLIAMS, LAMBERT & LANCE, 1966, p.428). The actual implementation of this technique was greatly simplified by using the I.M.S.L.[6] computer library sub-routines "OCLINK" and "USTREE".

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[6]IMSL = International Mathematical and Statistical Libraries, 6th floor, GNB Building, 7500 Bellaire Blvd., Houston, Texas, 77036.

TABLE 4

Factor scores

| FACTOR | GENERAL | NUTRIENTS | WATER | TEXTURE | REACTION |
|---|---|---|---|---|---|
| EIGEN VALUE | 12.78 | 3.06 | 2.33 | 1.98 | 1.62 |
| % EXPL. | 42.62 | 10.22 | 7.79 | 6.62 | 5.39 |
| CUML % EXPL | 42.62 | 52.84 | 60.64 | 67.26 | 72.66 |
| 1-ASP | 0.49 | 0.51 | -0.37 | -0.14 | 0.25 |
| 2-BEE | 0.60 | 0.25 | 0.44 | -0.22 | -0.24 |
| 3-BRO | 0.73 | -0.08 | 0.49 | 0.22 | -0.01 |
| 4-BRS | 0.62 | 0.02 | 0.56 | 0.13 | 0.05 |
| 5-CAB | 0.74 | 0.08 | 0.43 | 0.04 | -0.22 |
| 6-CAR | 0.59 | 0.54 | -0.28 | -0.24 | -0.05 |
| 7-CAU | 0.77 | 0.12 | 0.49 | 0.15 | 0.10 |
| 8-CEL | 0.61 | 0.06 | 0.33 | 0.04 | 0.37 |
| 9-COR | 0.64 | 0.24 | -0.07 | -0.18 | -0.12 |
| 10-CUC | 0.81 | 0.08 | -0.04 | 0.06 | -0.01 |
| 11-PEA | 0.70 | -0.53 | -0.08 | -0.20 | -0.06 |
| 12-PEP | 0.66 | 0.00 | 0.16 | 0.45 | -0.29 |
| 13-LET | 0.69 | 0.35 | 0.00 | -0.39 | -0.10 |
| 14-ONI | 0.74 | 0.38 | -0.10 | -0.37 | -0.06 |
| 15-PAR | 0.67 | 0.54 | -0.25 | -0.16 | -0.06 |
| 16-POT | 0.55 | 0.36 | 0.18 | 0.09 | -0.04 |
| 17-RAD | 0.68 | -0.35 | -0.16 | -0.24 | -0.26 |
| 18-BNS | 0.78 | -0.43 | -0.09 | -0.07 | 0.03 |
| 19-SPI | 0.57 | 0.03 | -0.31 | 0.49 | -0.12 |
| 20-SQU | 0.64 | 0.02 | -0.24 | 0.49 | -0.27 |
| 21-TOM | 0.54 | 0.05 | -0.32 | 0.35 | 0.12 |
| 22-TUR | 0.65 | 0.11 | -0.39 | 0.26 | -0.06 |
| 23-APL | 0.58 | -0.23 | 0.12 | -0.29 | 0.35 |
| 24-BLB | 0.47 | -0.39 | 0.04 | -0.31 | 0.38 |
| 25-RAS | 0.66 | 0.04 | -0.69 | -0.11 | 0.25 |
| 26-STB | 0.63 | -0.06 | -0.03 | 0.27 | 0.53 |
| 27-BAR | 0.61 | -0.52 | -0.24 | -0.15 | -0.28 |
| 28-OAT | 0.60 | -0.22 | -0.34 | 0.18 | 0.45 |
| 29-RYE | 0.75 | -0.44 | -0.13 | 0.04 | -0.12 |
| 30-SOY | 0.49 | -0.51 | 0.00 | -0.25 | -0.24 |

Complete descriptions of linkage analysis may be found in ANDERBERG, (1973, p.131-139); HARTIGAN, (1975, p.191-214); and YEATES, (1974, p.93-97).

The crop groups formed by linkage analysis were quite similar to those suggested by P.C.A. However, the cut-off correlation level at which these major groupings occurred was at times very low ($\phi$= 0.30). In these cases raising the correlation level created groups so small that they corresponded poorly with the clusters suggested by P.C.A.

In addition several of the groups formed by linkage analysis contained crops which, when cross-referenced with the original data matrix, had important soil property preferences which did not correspond well with the preferences of the rest of the group. Information analysis was chosen to help clarify the groupings.

2.2.2.4 Information Analysis

Described in detail by WILLIAMS & DALE, (1965); WILLIAMS, LAMBERT & LANCE, (1966); and DALE & ANDERSON, (1972), the actual mechanics of this technique are very similar to those of linkage analysis except that instead of using a nearest neighbor approach to update the $\Delta I$ statistic matrix a centroid algorithm is used. When group X is formed by joining individuals (or groups) Y and Z, all the records and coefficients involving either Y or Z are deleted. Instead of replacing them with one or other of the values of Y or Z (nearest neighbor) the algorithm returns to the data matrix. A new $\Delta I$ is then calculated between the new group X and all remaining crops or groups.

The groups suggested at reasonable entropy levels in information analysis, and the data clusters projected by P.C.A. were very similar to one another. This mutual support enabled the following examinations to be made before crop groups were finalized.

1. The numerous clusters outlined in P.C.A. could be checked by information analysis to determine the amount of information lost by considering component members of a cluster as a single group.

2. The potential groups could then be cross-referenced with the original data matrix to ensure that the soil conditions of that group were indeed homogeneous.

By juggling potential groups back and forth between the strength of their loadings on different factors, the degree of information lost by fusion, and known soil conditions as revealed in the data matrix, five main groups were formed. They are seen as very efficient both with respect to internal homogeneity of soil requirements as well as with respect to the amount of information lost from the system by way of their creation.

## 2.3 RESULTS

In all, five groups were finalized which represent the dimensions of variation present within the total set of crops. In addition there remained seven crops which, by nature of their particular soil requirements, did not appear to fit into any one group.

### 2.3.1 Group A

Group A is composed of six crops: barley (BAR), beans (BNS), field peas (PEA), radishes (RAD), rye (RYE), and soybeans (SOY). Of all the groups examined it is one of the most homogeneous with respect to soil requirements. In P.C.A., it consistently maintained tightly grouped clusters when graphed against all combinations of factor pairs. Most of these clusters were well separated (ie. distinct) from the rest of the crop population. Some, however, merge with group B, and occasionally with group C as well. See Appendix D for graphical representation of crop group factor loadings plotted against all pairwise combinations of the first five factors.

This group is also well defined by linkage analysis in which it appears at a correlation level of 0.475.

Information analysis provides the final confirmation of the validity of this group. The total entropy of the set of crops was calculated to be 1.11. This group is formed at a level of 0.4729. It is composed of the leguminous field crops (field peas, soybeans, and beans) plus two small grain field crops (barley and rye), and a root crop (radish). Group A crops prefer moderately acid to slightly alkaline sandy-loams to loams containing moderate nutrient reserves. They are not especially deep rooting but require lots of water in well-drained sites.

## 2.3.2 Group B

Group B is composed of seven crops: asparagus (ASP), beets (BEE), carrot (CAR), corn (COR), lettuce (LET), onion (ONI), and parsnip (PAR). It appears to be the second most homogeneous group of crops derived in this study. P.C.A. displays this group in relatively well defined, distinct clusters when graphed against most pairs of factors. This is especially true when one of these is factor 2, (nutrient requirements). In cases where this group is graphed against factors other than nutrients it forms a close association with group A. Therefore, apart from nutrient requirements, these two groups can grow well under very similar soil conditions. P.C.A. suggests that this is especially the case with regard to pH, soil moisture and drainage requirements.

Linkage and information analysis agree in general with the clusters suggested by P.C.A. The linkage algorithm unites the core of this group (parsnip, carrot, asparagus, onion, lettuce, corn) at a correlation level of 0.368. In addition, it includes cucumber (CUC) in its midst, but fuses beet (BEE) to what is defined below as group C. Information analysis, although recognizing the core, represents this group in a slightly different way.

Here, asparagus, lettuce, onion, carrot, and parsnip are joined at $\Delta I = 0.4765$ while both beet and corn are included in other groups.

A final decision as to the crops to be contained in this group thus became a classical case of reviewing factor loadings, fusion levels, and perhaps most importantly, the original data matrix in order to derive groups which made practical sense. BEE, for example, grows optimally under a wider pH range than most group C crops. In addition it grows well in muck soils and has very high NNN requirements whereas most group C crops do not. These characteristics made it much more suited to group B.

### 2.3.3 Group C

The third group consists of the cole crops: broccoli (BRO), Brussels sprouts (BRS), cabbage (CAB), and cauliflower (CAU). These late-harvested, cool season crops form tight clusters when graphed by P.C.A. against all pairs of factors. Thus the homogeneity of requirements of this group, as confirmed by an examination of Table 15 in Appendix E is assured.

Linkage analysis does not single out this group. Cauliflower, cabbage, beet, potato, Brussels sprouts, broccoli, and green pepper are joined where $\Phi = 0.312$. Information analysis, on the other hand, fuses broccoli, Brussels sprouts, cabbage, and cauliflower together at an entropy level of only 0.3432. Remember, of course, that high values of $\Phi$ and low values of $\Delta I$ mean strong pairwise association.

### 2.3.4 Group D

Group D is composed of three crops: spinach (SPI), squash (SQU), and green pepper (PEP). It is a readily distinguishable cluster in P.C.A. and in four out of nine cases it emerges as a tightly packed, isolated group, ostensibly showing different characteristics from the rest of the crop population as a whole. In the other five cases the clusters are less readily identified because it merges in close association with either group C, A, or other individual crops which, by their particular unique soil requirements, were not grouped.

Linkage analysis identifies the core of this group (spinach, squash) at a correlation level of 0.734 but fails to recognize green pepper as a potential member. Instead it prefers to place this crop with broccoli which eventually becomes a member of group C at the 0.312 level.

Information analysis, on the other hand creates this group at an entropy level of 0.3897.

### 2.3.5 Group E

Beyond the four major groups identified above one other pair of crops was considered to have soil requirements sufficiently similar to warrant their grouping. These were strawberry (STB) and oats (OAT). In over half of the factor graphs these two crops form a distinct and isolated cluster. In other cases group E exists in close association with other groups, particularly groups C and D.

Linkage and information analysis also recognize this group. The former creates the fusion at a correlation level of 0.734 and the latter at a very low entropy level of 0.2236.

2.3.6 Ungrouped Crops

In addition to the five groups established by P.C.A., linkage, and information analysis there remained several crops which, by nature of their specific and sometimes particular soil requirements did not warrant being placed in one specific group. Blueberry (BLB), for example, has pH requirements which would be toxic to most other crops. It was, therefore, left ungrouped. Most other crops meet the partial requirements of several different groups while never meeting all the requirements of one group exclusively. These crops are tomato (TOM) (associated with groups A,B,D,E) and apple (APL) (associated with groups A,B,D,E). Finally, two crops, potato (POT), and raspberry (RAS) are sometimes associated with a particular group, but more often, are isolated, unique individuals. Potato, for example, finds itself most strongly associated with group B crops but is frequently depicted by P.C.A. factor graphs as possessing somewhat unique soil requirements. This is due, it is suspected, to a lack of a characteristic pattern of soil requirements for optimum growth on the part of potato. Similar conclusions were made with respect to the status of raspberry in the grouping procedure.

A scenario has now been established which contains five crop groups and five individual crops. Any or all of these groups or individuals could be employed as land-use type(s) in the soil suitability methodology developed below. A full scale project concerned with the eventual land evaluation of an area would employ all the members of the scenario as well as other agricultural and non-agricultural use types. The results would be several sets of suitability indices (one for each use type).

In this thesis time, labour, and capital constraints permitted only one crop group to be input as a use type into the soil suitability model. Crop group A was chosen for two reasons. First, it was one of the most homogeneous groups derived. Second, and most important, crop group A's members are primarily field crops. It is similar to that crop group for which a soil capability study was made in the study area by MARSHALL et al, (1979).

The hypothesis can be made that suitability indices derived here should correlate well with capability classes if the former are accurate. Thus, the possibility exists of testing the results generated by the suitability model. This matter is discussed more fully in Chapter 4.

# Chapter III

# SOIL SUITABILITY ANALYSIS

"Land classification itself is not an end. It is the means toward an end. The desired result for which land classifications are created is an improved physical and economic environment in which people can live more productive and satisfying lives." (F.A.O., 1974, p.1)

## 3.1 INTRODUCTION

A similar problem is faced by many land-use planners, foresters, agriculturalists and others concerned with rating the quality of land for different uses, (NIX, 1968, p.77). Each of these professionals must have:

1. a knowledge of the landscape itself: a data base in which those parameters most relevant to the specific land-use (or uses) under consideration have been identified, measured, and spatially delineated across the landscape being scrutinized.

2. an understanding of the needs of each land-use type: a knowledge of how variations in the conditions or states of each parameter in isolation affects the performance of the use.

3. a method of rating how well a particular landscape is adapted to specific land-use types or, in other words,

a system which determines how well (1) and (2) above match[7].

The second stage of research in this thesis involved designing and implementing a method which, it was hoped, would accurately generate indices of current or "actual" land suitability for different land-use types.

The "testing ground" for this particular study was soil suitability of specific sites in S.E. Nepean Township for crop group A. However, it should be re-emphasized that the operating characteristics of the method described below are seen as applicable to a variety of working scales as well as to land-use types not necessarily agricultural in nature.

The next section of this chapter describes the desirable characteristics of a method of deriving soil suitability, outlines a way of operationalizing these concepts into a computer model, and illustrates the model's operation with a simple example. Section 3.3 is devoted to a discussion of the test data subsequently input into the model.

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[7]An interesting discussion on the interpretive value for land-use planning of different rating scales is given by CENTRE FOR RESOURCES DEVELOPMENT, (1977, p.6-52) and BRINKMAN & SMYTH, (1973, p.38-40).

## 3.2 THE MODEL

The purpose of the technique outlined below was to assign numerical indices or rating points to specific, internally homogeneous land units. These indices were to represent the units' current or actual land suitability (as defined in Chapter 1) for producing or sustaining different land-uses.

### 3.2.1 General Characteristics

As a starting point the definition of a parametric approach, given by RIQUIER, (1974, p.42), and quoted in Section 1.2.4 was used. In the light of several strong criticisms made by VINK in BRINKMAN and SMYTH, (1973, p.38), concerning the ability of the parametric models so far developed to actually meet this definition, three additional desirable properties were added:

1. Because the same soil factor often has a different influence on plant production (or other uses) depending on its interactions with other factors, these interactions were taken into account. This is a principal characteristic of the "integrated" approach described by MABBUTT, (1968, p.16-17).

2. It was also decided to pay strong heed to the particular needs of specific land-use types (such as those created in Chapter 2) instead of assessing sites for agriculture in general.

3. A system of signalling potential limiting factors at specific sites was also seen as a useful feature of any method used to derive land or soil suitability.

In addition, three other characteristics were incorporated by this author:

4. Providing that a base data has already been gathered, the model should be quickly and easily implemented in order to alleviate, if only partially, many of the problems faced by overworked pedologists, and agronomists as mentioned by STEELE, (1967, p.1) and alluded to by the SOIL SURVEY STAFF, (1962, p.365).

5. Providing that necessary input data is available, the model should be capable of producing results which are consistently and scientifically reproduceable by researchers employing it.

6. In these times of financial restraint, the model should be inexpensive to operationalize.

With these criteria providing a conceptual framework, the technique described below was developed.

### 3.2.2 Elements of the Model

Two mathematical constructs form the heart of the soil suitability model. The first is a row vector, $_1[S]_m$, representing a single site or homogeneous land area. It is composed of binary entries a(j). Each entry represents one of the 'm' soil variable states or classes into which those variables pertinent to the land-use under consideration have been divided*. An entry a(j) equal to 0 signifies that variable state 'j' is not present at the site. An a(j) equal to 1 is present at the site.

Since it is assumed that each site or map delineation is a relatively homogeneous entity with respect to land conditions it follows that, at least theoretically, only one class per variable should have an entry equal to 1. In reality this should usually be the case, depending, of course, upon the scale at which pedoecological data has been identified and mapped. Since, however, most variables are measured on a continuous scale, each variable state usually represents at least a narrow range of values. Small variations within a site are therefore usually accounted for by one variable state. In this study, for example, the variable called soil depth (DEP) was divided into five variable states or classes. Class 1 ranged from 0.3 - 0.8 metres; class 2 spanned 0.9 - 1.4 metres, and so on.

It should be noted that the proper operation of the model hinges upon allowing only one class per variable equal to 1. Variables must, therefore, be subdivided in such a way as to accommodate slight internal variations within sites and, at the same time, retain relevance to the land-uses under consideration.

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*The use of matrices to store and manipulate data was inspired by the author's thesis supervisor, Dr. M. PHIPPS.

In most studies of soil suitability the researcher will be concerned with a region which has been subdivided into homogeneous land or soil areas. In other words, instead of examining a single site, many sites will be assessed. This is the case in this thesis. Numerous sites may be accommodated by modifying 1[S]m so that it becomes n[S]m. The n[S]m is a matrix composed of 'n' row vectors of the type described just above. Each site is represented by a unique row vector in the n[S]m matrix as shown in Figure 3.

| | VAR1 | | | | VAR2 | | | | VAR3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1a | b | c | d | 2a | b | c | d | 3a | b | c | d |
| SITE A | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| SITE B | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| SITE C | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

soil variables
state "d" of VAR3
not present at SITE B
present at SITE C

Figure 3: A hypothetical 3-row site matrix

The second major element of the model is a matrix, denoted here as m[U]m. This matrix expresses the degree to which the states of soil variables, used in the creation of n[S]m, actually meet land or soil requirements for a single land-use type. The entries, a(x,y) of each row and each column correspond to a single variable state and may be labled in the same way as the 'j' or horizontal axis of n[S]m, (see Figures 3 and 4).

Encorporated into m[U]m are two kinds of numerical values. The first is a rating representing the potential suitability of each variable state for the land-use being examined, assuming that other variable classes are invariant and optimum. These ratings lie in the "m" entries making up the diagonal of the matrix. They correspond, in numerical terms, to the shades of white-grey-black employed by McHARG, (1969, p.32-41), in his land-use planning maps.

If "v" equals the number of pertinent variables in m[U]m then the second type of value lies in the (v•(v-1)/2) submatrices positioned below the diagonal. These contain the pairwise interactions which occur between combinations of different variable states. Interactions are defined here as the <u>difference between</u> the rated effect that two coexisting variable states have, and the effect generated by each variable state in isolation (assuming other variable states constant), upon a contribution to soil suitability. They may be positive (synergistic), neutral (no effect or interaction), or negative (limiting). RUSSELL, (1973, p.55), states that:

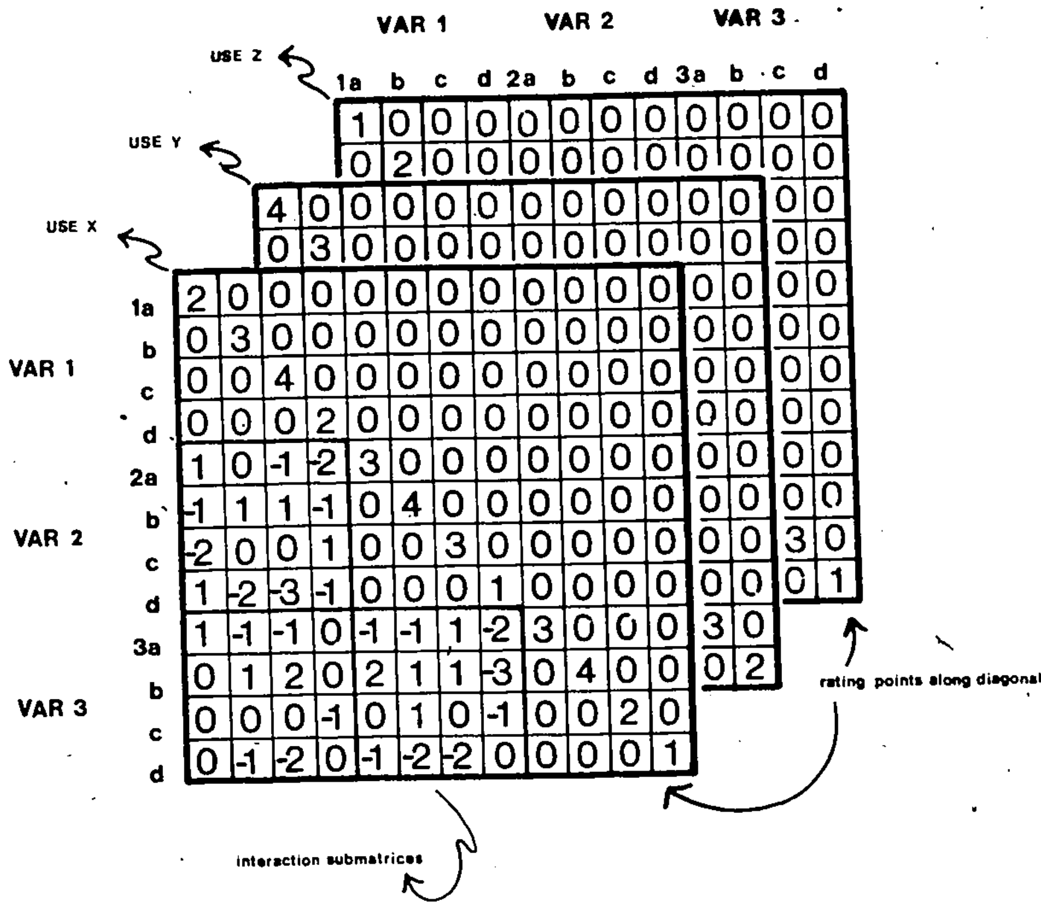
> "...if two factors are limiting, or nearly limiting growth, adding [correcting] one of them will have little effect on growth while adding [correcting] both together will have a considerable effect. Two such factors are said to have a large positive interaction in such circumstances, for the response of the crop to both together is larger than the sum of the responses to each separately. If the crop responses to the two factors together equalled the sum of its responses to each separately, we would say that two factors showed no interaction...and if the response to the two factors together was less than the sum of the responses to each factor separately, they are said to have a negative interaction with each other."

In practical terms, the interaction values employed in this thesis are an attempt to solve one of the problems of parametric approaches brought to light by VINK in BRINKMAN and SMYTH, (1973, p.38), above, and discussed in Chapter 1.

The upper half of m[U]m (ie. those entries to the right of the diagonal) as well as those entries lying between the diagonal and the adjacent submatrices below it are equal to 0. This creates, in essence, a triangular matrix, (CAMPBELL, 1968, p.61).

Although not the case in this thesis for reasons given at the end of Chapter 2, the researcher will frequently be concerned with the assessment of soil suitability for several different land-use types in an area. Each type will presumably perform differently under a specified set of soil conditions. The ratings along the diagonal of m[U]m as well as interactions will be unique to the use being studied. Therefore, each use type will require its own 'space' within the suitability model. The creation of this space is achieved by transforming m[U]m into a three-dimensional data array denoted here as $m[\underset{u}{U}]m$. The $m[\underset{u}{U}]m$ is a three-dimensional data table composed of 'u' m[U]m matrices. Each separate matrix, represents a unique land-use type possessing its own ratings and interactions. As the reader should have surmised, the creation of this third dimension of m[U]m is an attempt to solve another of the key problems of parametric approaches put forth by VINK and discussed in Section 3.2.1 above. Figure 4 is an example of a hypothetical $12[\underset{3}{U}]12$ array[9].

Figure 4: A hypothetical 12[U/3]12 array

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[9] In actual fact these 3-D arrays or multidimensional tables are not found in matrix algebra. They have, however, proved to be a most convenient form of visualizing the storage and manipulation of large and complex data sets particularly where computer programming is involved.

### 3.2.3 Operation

Those readers requiring a less formal discussion of the soil suitability model's operation are referred to Subsection 3.2.4, below for a simple example.

Suitability indices are calculated in a series of three basic steps. A fourth operation which singles out potentially strong limiting factors is discussed at the end of Appendix F. The explanation restricts itself to the calculation of one suitability index on one site for one land-use type. Therefore the site matrix, ${}_{n}[S]_{m}$, is actually a row vector, ${}_{1}[S]_{m}$, and ${}_{m}[\underset{u}{U}]_{m}$ is simply ${}_{m}[U]_{m}$.

1. The first operation is to calculate the dot product[10] of the row vector, ${}_{1}[S]_{m}$, with ${}_{m}[U]_{m}$. This yields by definition another row vector, denoted here as ${}_{1}[I]_{m}$. Contained in its "m" columns are the ratings, interactions, and combinations of the two, associated with the land-use U at site S. The equation takes the following form:

$$3.2.1 \qquad {}_{1}[I]_{m} = {}_{1}[S]_{m} \cdot {}_{m}[U]_{m}$$

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[10] For those unfamiliar with matrix multiplication see a) CAMPBELL H.G., (1968) b) SCHNEIDER, H. & G.P. BARKER, (1968), or c) DENIS-PAPIN, M. & A. KAUFMAN, (1969).

2\. ${}_1[I]_m$ represents an intermediate step in the calculation of suitability indices. Before the latter can be derived I must first be transposed. Such a transformation yields a column vector, ${}_m[I.t]_1$.

3\. The final set of calculations is similar to the first. The basic operation is a dot product of ${}_1[S]_m$ with ${}_m[I.t]_1$ to create a scalar, ${}_1[Cs]_1$. ${}_1[Cs]_1$ is an index of current or actual suitability of the sites described in ${}_1[S]_m$ for the use represented by ${}_m[U]_m$.

Calculated by the equation:

$$3.2.2 \qquad {}_1[Cs]_1 = {}_1[S]_m \bullet {}_m[I.t]_1$$

it is, essentially, a summed synthesis of those rating-interaction combinations described above which are actually found at the site and are relevant to the use in question.

The three steps outlined above embody the basic operating characteristics of the model. Figure 5 is a diagrammatic representation of these steps. It is characterized by a simplicity and an elegance of operation in which interactions are systematically accounted for. The expansion of the model to accommodate many sites is made by adding rows to ${}_1[S]_m$. ${}_1[I]_n$ increases its rows and ${}_m[I.t]_1$ expands its columns accordingly. Several uses can be incorporated by adding a third dimension to m[U]m as described above. 1[Cs]1 expands with these additions. Under one use it gains successive rows as the number of sites increases. It should be noted that each additional row entry is the product of one row vector in n[S]m by one column vector of m[I.t]n. Then with the introduction of more land-use types, columns are appended. Further elucidation by means of an example may be found below. Subsequently translated into Fortran[11] by the author, the model was entitled LASTAN[12]. LASTAN, in its present state, can handle up to 150 sites and 5 different land-use types, described by a maximum of 10 factor variables divided into a total of 50 variable states (see Appendix F).

### 3.2.4 An example

To further clarify how this model works an example using hypothetical input data has been set up. It involves three sites, each of which is described by the variables: texture (TEX), topography (TOP), and drainage (DRA). Each variable has been divided arbitrarily into four classes or states as shown in Table 5.

For simplicity's sake it was decided to use the same site matrix, 3[S]12, as shown in Figure 3 above. An examination of

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[11]Actually WATFIV "Structured" Fortran.

[12]LASTAN = Land Suitability Analysis. "Land" was used instead of "Soil" for reasons discussed in Chapter 5.

Figure 5: Diagramatic representation of soil suitability model, LASTAN

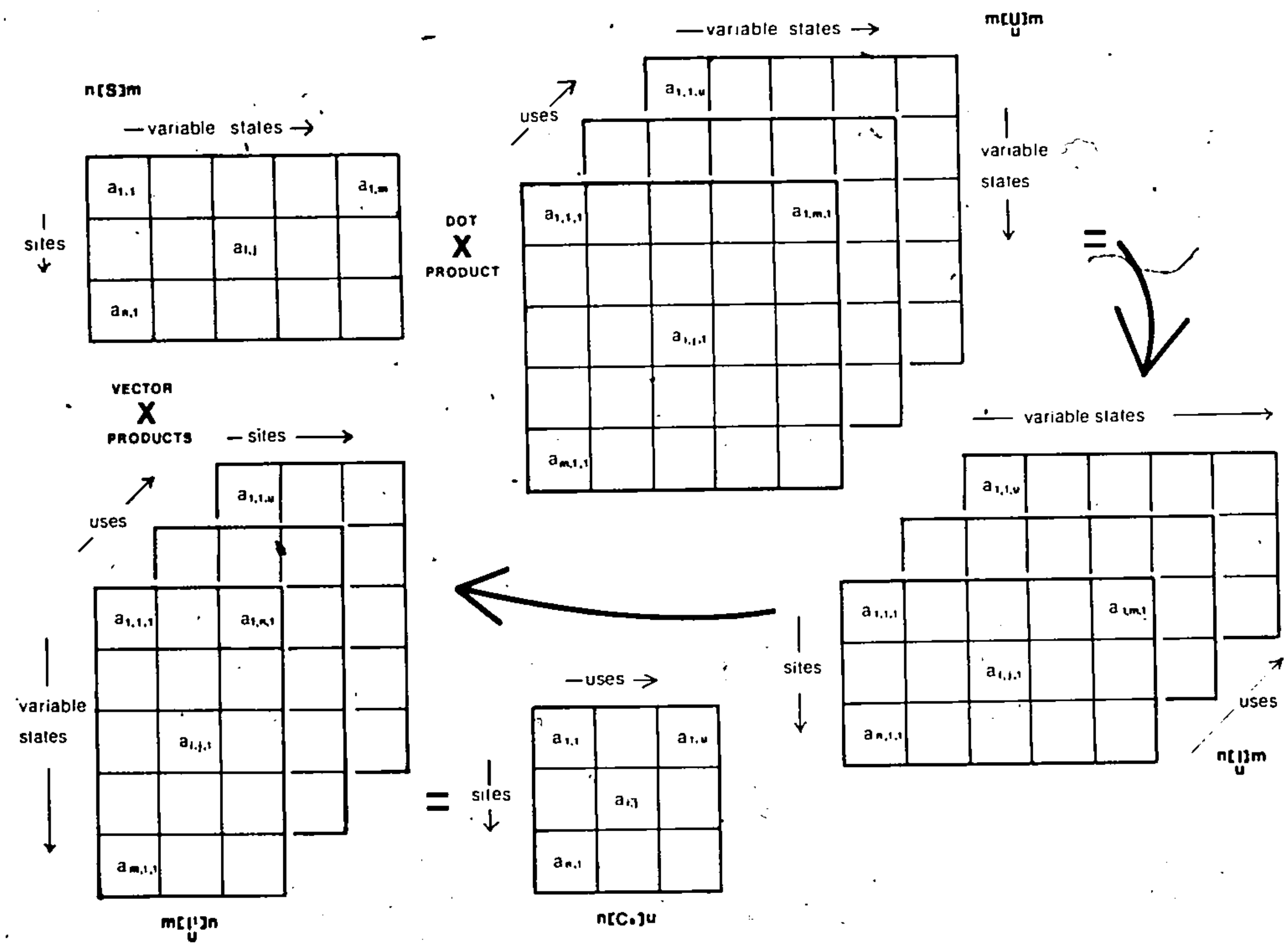


TABLE 5

Description of variables, classes, and rating system used in soil suitability example

| VARIABLE NAME | | CLASS I.D. | DESCRIPTION | RATING SYSTEM |
|---|---|---|---|---|
| TEX | Texture | 1a | Sand | |
| | | 1b | Sandy Loam | 4 - Excellent |
| | | 1c | Clay Loam | |
| | | 1d | Clay | 3 - Good |
| TOP | Topography | 2a | Depressional | 2 - Poor |
| | | 2b | Flat | |
| | | 2c | Gently sloping | 1 - Unsuited |
| | | 2d | Strongly sloping | |
| DRA | Drainage | 3a | Excessive | |
| | | 3b | Good | |
| | | 3c | Imperfect | |
| | | 3d | Poor | |

this matrix in conjunction with Table 5 reveals that site A is characterized by sandy-textured surface soils, a gently sloping topography, and excessive drainage or a droughty moisture regime. In reality such soils fit a cursory description of landscape units actually found in the study area, particularly those of the Uplands Association, (MARSHALL et al, 1979, p.105-106). Site C, in contrast is poorly drained, somewhat depressional, and is composed primarily of a clayey surface texture. It closely resembles several members of the Dalhousie Association, (MARSHALL et al, 1979, p.57). Site B is well-drained, level, and of a sandy-loam texture. Some of the soils in the Jockvale Association have similar properties, (MARSHALL et al, 1979, p.72).

Each site was rated for the production of barley under the assumption that above-average management levels would be employed.

Barley has high drainage requirements, prefers flat to gently sloping terrain and clay-loam to silt-loam textures. With these optimum conditions in mind the variable states and interactions occurring between states were rated in a hypothetical 12[U]12 matrix. This matrix is identical to the first layer of 12[$\underset{3}{U}$]12 shown in Figure 4 above.

Again in the interests of simplicity, ordinal data, based upon a rating system devised by the author (see Table 5, above) and information available in BLAND, (1971, p.71-76); DUBE, (1976, p.87); HUGHES & HENSON, (1957, p.75-130,309-314); LOGSDON, (1977, p.157); MACK, (1965, p.340-345), WEAVER, (1926, p.175-179), and others, was used.

Stage one in the calculation of 3[Cs]1 was to first obtain 3[I]12 and its transpose 12[I.t]3. A quick run-through of the calculations of entries a(1,1), a(1,3), and a(1,7) of 3[I]12 should serve to demonstrate both how the rest of the matrix was derived and the significance of the entries in each row of I.

I a(1,1) was calculated by the following equation:

$$3.2.3 \qquad I\ a(1,1) = \sum_{i=1}^{m} (\ S\ a(1,i) \cdot U\ a(i,1)\ )$$

where m = number of columns in 3[S]12 and the number of rows in 12[U]12 a = an entry in either S or U

It is represented diagrammatically by Figure 6 below.

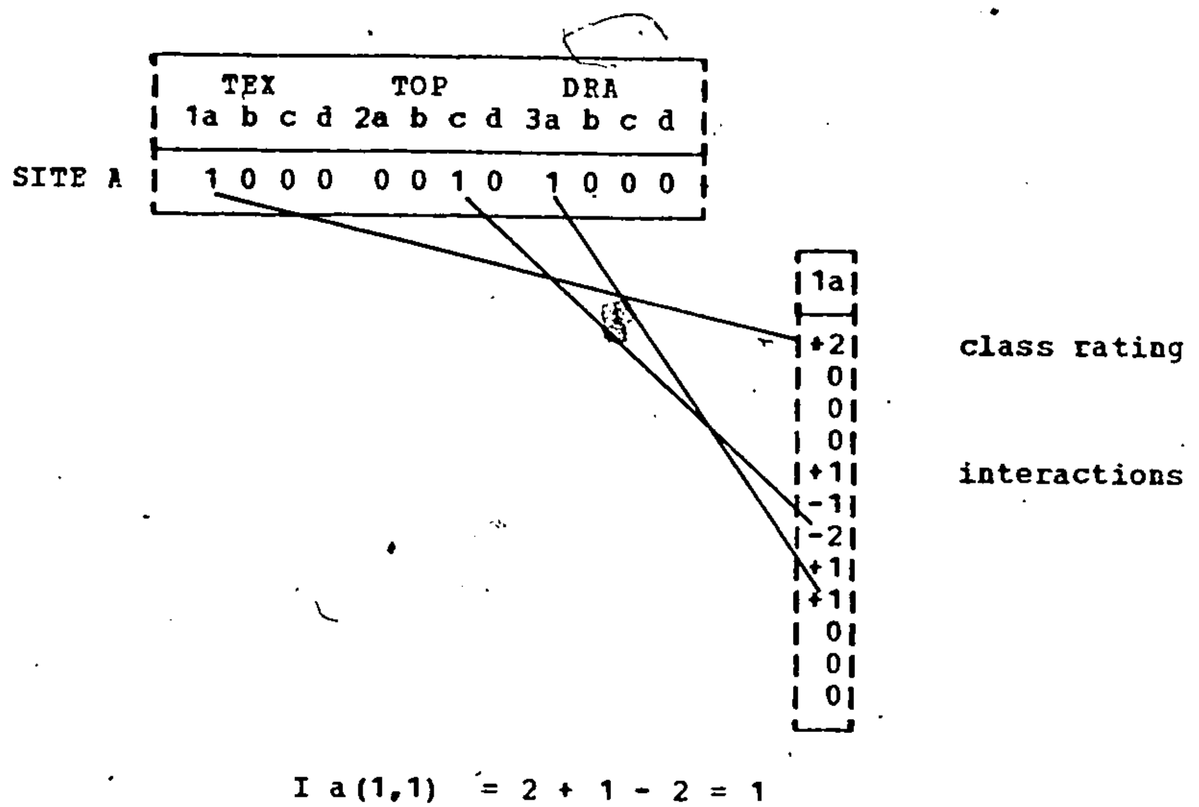
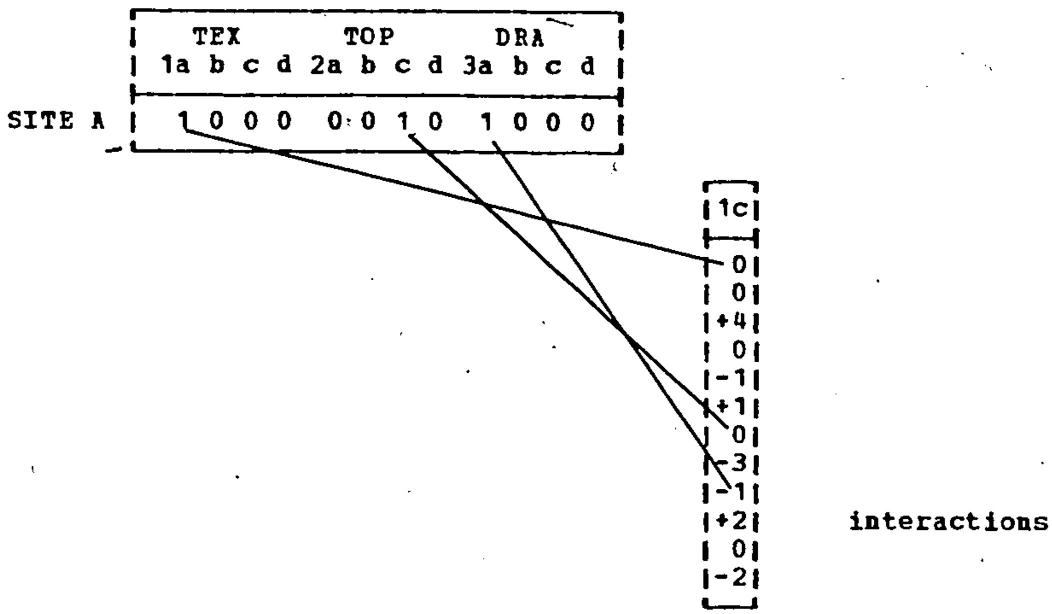



Figure 6: Calculation of entry a(1,1) of 3[I]12

This entry, as shown below, is considered relevant or useful as partial input to the final suitability rating of Site A for barley because it embodies the rating of a condition present in A with interactions associated with that condition and other variable states.

The entry I a(1,3), on the other hand, proves irrelevant. It is calculated by the equation 3.2.4 and is represented by Figure 7 below.

3.2.4 $$I\ a(1,3) = \sum_{i=1}^{m} ( S\ a(1,i) \bullet U\ a(i,3) )$$




$$I\ a(1,3) = 0 + 0 - 1 = -1$$

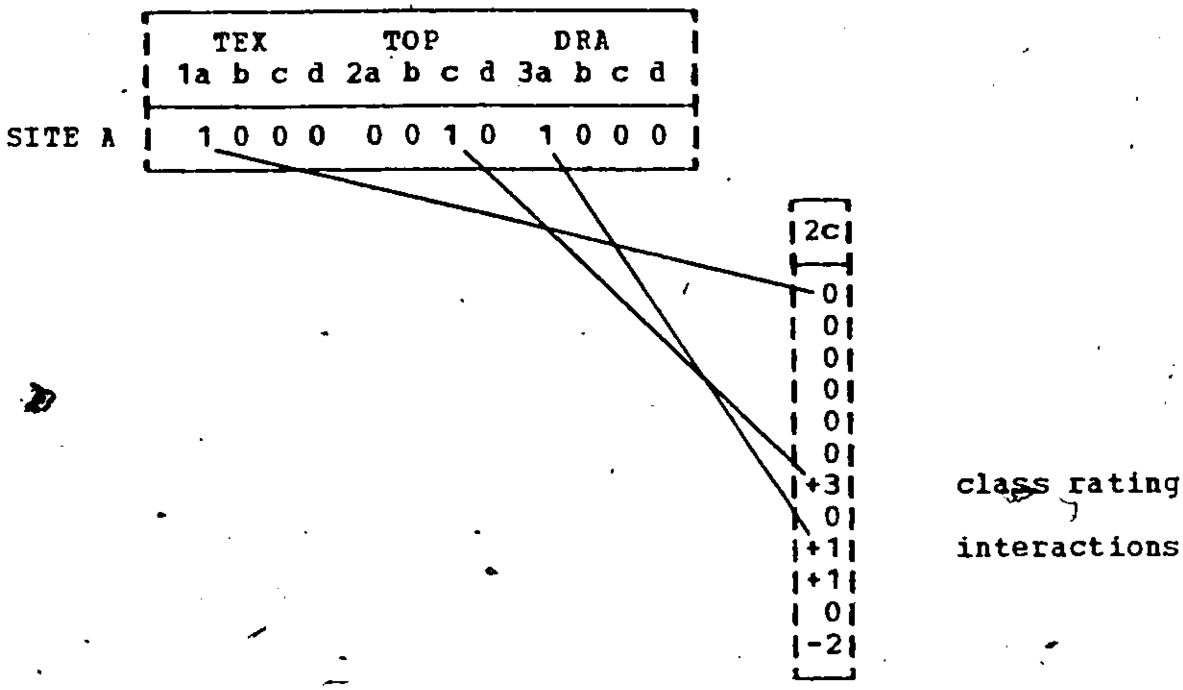
Figure 7: Calculation of entry a(1,3) of 3[I]12

Notice that the result, -1, represents only one interaction which does not occur in conjunction with conditions actually present in Site A.

Calculating I a(1,7) yields another result relevant to Site A. Here a value of +4 was obtained from the equation:

3.2.5 $$I\ a(1,7) = \sum_{i=1}^{m} ( S\ a(1,i) \bullet U\ a(i,7) )$$

Figure 8 is a diagram representing this calculation.




I a(1,7) = 0 + 3 + 1 = +4

Figure 8: Calculation of entry a(1,7) of 3[I]12

Following through the rest of stage one calculations allowed the derivation of 3[I]12 shown below with its transpose 12[I.t]3 in Figure 9.

The final step in this example involved obtaining the vector products of each row of 3[S]12 by 12[I.t]3. This operation served to extract and combine the relevant entries of I into a series of suitability indices displayed in the column vector 3[Cs]1 in Figure 10.

3[I]12

$$\begin{array}{l} \text{SITE A} \\ \text{SITE B} \\ \text{SITE C} \end{array} \begin{pmatrix} +1 & -1 & -1 & +1 & -1 & -1 & +4 & -2 & +3 & 0 & 0 & 0 \\ -1 & +5 & +3 & -1 & +2 & +5 & +1 & -3 & 0 & +4 & 0 & 0 \\ -1 & 0 & -1 & +1 & -1 & +2 & -2 & 0 & 0 & 0 & 0 & +1 \end{pmatrix}$$

12[I.t]3

$$\begin{array}{ccc} A & B & C \end{array}$$
$$\begin{pmatrix} -1 & -1 & 0 \\ -1 & +5 & 0 \\ -1 & +3 & -1 \\ +1 & -1 & +1 \\ -1 & +2 & -1 \\ -1 & +5 & +2 \\ +4 & +1 & -2 \\ -2 & -3 & 0 \\ +3 & 0 & 0 \\ 0 & +4 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & +1 \end{pmatrix}$$

Figure 9: 3[I]12 and its transpose 12[I.t]3

$$3[Cs]1 = \begin{bmatrix} 8 \\ 14 \\ 4 \end{bmatrix} \quad \text{(with interactions)}$$

Figure 10: The suitability vector, 3[Cs]1

These results show that, for barley, Site B rates highest in terms of current suitability. Sites A and C follow respectively. A re-examination of 3[S]12 and 12[U]12 shows that the index value, 14, for Site B was obtained by first adding the rating points given to the relevant site conditions. These were +3 (sandy-loam) +4 (flat topography) +4 (good drainage). Then an interaction of +1 each, between topography and drainage, topography and texture, plus drainage and texture, added up to a further 3 points to give a total of 14.

Had interactions NOT been accounted for the lower half of 12[U]12 would have contained all zeros and the resultant 3[Cs]1 would have looked like Figure 11.

$$3[Cs]1 = \begin{bmatrix} 8 \\ 11 \\ 7 \end{bmatrix} \quad \text{(without interactions)}$$

Figure 11: Hypothetical 3[Cs]1 suitability vector

These indices nearly equate Site A and C together, a fact which, considering barley's aversion to poorly drained sites, does not realistically represent the relative difference in suitabilities of the two sites for this crop. The incorporation of interactions, therefore, helps to accentuate the effect of relationships occurring between variables. The result, it is felt, is a clearer, more accurate representation of reality. This statement is attested to in Chapter 4, below.

## 3.3 THE DATA

### 3.3.1 A framework

The choice of data used to implement the LASTAN model was controlled by several guidelines set up to ensure meaningful output. They were:

1. that the data (ie. variables, classes, rating points, and interactions) to be used yield results consistent with and relevant to: a) the concepts of soil suitability discussed in Chapter 1; b) the uses (ie. crop group A) for which assessment was to be made; and c) the assumptions made regarding climatic variation and levels of management over the study area.

2. that only variables and ranges of associated classes which vary significantly within the study area be used in the construction of n[S]m and m[U]m in order to keep the LASTAN program as efficient as possible.

3. That data not available both quickly and at low cost to the author be ignored because of time constraints and financial considerations. This restricted the amount of actual field work that could be performed and shifted the focus of data collection to the soil surveys already completed within the study area.

4. That the choice of data used (within the constraints mentioned above) be made in reference to: a) potential users of the results (ie. county farm planners, individual farmers, and agricultural extension agents); b) the overall physical scale of the project; c) the kinds of land-use decisions that might be made in the light of the results, (BRINKMAN & SMYTH, 1973, p.31); and, most importantly, d) the possibility of testing results obtained here against an accepted norm: the capability

classes derived by the Land Resource Research Institute, (MARSHALL et al, 1979), for the same area.

### 3.3.2 Variable selection

Crop group A was originally described by and derived from manipulations of the soil factors SPH (reaction), TEX (surface texture), NNN, PPP, KKK (available N, P, and K), ORD (optimum rooting depth), WCN (water consumption), and ODR (drainage requirements). These factors possess values for optimum growth which vary significantly across the set of crops. They are thus well suited to the methods of numerical taxonomy employed above. Those soil attributes chosen to calculate soil suitability had a different purpose. They had to relate to spatial variations across a landscape as opposed to requirement variations for a set of crops. Thus, from the original set used in crop grouping, two were deleted and replaced with two new soil variables and one variable was modified in order to comply with this new purpose.

First, the variable NNN was dropped. Available N was considered relatively unimportant here because its seasonal variations are so great. Thus measures of its value at one point in time have very little meaning[13]. In addition, this plant nutrient is so cheaply and easily replenished either by additions

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[13]See BRADY, (1974, p.422-44); and DAVIES et al, (1975, p.28-35) for a general review of the nitrogen cycle, its seasonal fluctuations, and its importance to crop growth.

of fertilizers and animal manure or by rotations with leguminous crops that its importance to soil suitability was seen as negligible within the context of assumed management levels discussed in Chapter 1.

Second, the variable WCN (water consumption) was also dropped. It is recognized that WCN is one of the most important land factors affecting crop growth. However, it was not used in the soil suitability analysis for two reasons:

1. Although crop water consumption data is available, (TAN, 1978, pers. comm.), very little data (if any) exists on rates of water <u>availability</u> for map units within the study area. The development of a sample design to independently measure this variable was not feasible within the scope of this research.

2. In general, excess water and not a lack of it is the predominant limiting factor of SE. Nepean soils, (DUMANSKI et al, 1978, p.34,38). The drainage variable, DRA, a modified version of ODR, was expected to account for such land characteristics.

Third, two new variables, SLO (slope) and STO (stoniness) were added to the system. Not used in crop grouping for reasons discussed in Chapter 2, they were considered crucial to any study of soil suitability and were therefore introduced at this point.

With these adjustments, eight relevant variables became the means for describing and rating Nepean soils. They are SPH, TEX, depth (DEP), drainage (DRA), slope (SLO), stoniness (STO), PPP, and KKK. Of these, five were easily measured from data provided on the latest soils map of the area. Compiled by MARSHALL et al, (1979), this map was published at a scale of 1:25,000. The other three variables, SPH, PPP, and KKK were sampled in the field. A method suggested by HEEG, (1975) was employed. However it was slightly modified to fit this study's needs using suggestions made by MILLETTE & SEARL, (1968); and SEARL, (1966). Analysis of these samples was performed by the Department of Land Resources Science, University of Guelph, Guelph, Ontario. Field sampling also served as a partial confirmation of the easily recognized factors slope, drainage, depth (Class 1), texture, and stoniness whose initial values were extracted from the soils map. In one or two cases the author was obliged to make slight corrections when soils map data and values found at sites did not correspond. For example, the map delineation G1/2.2/3 was not mapped as having stoniness problems. All delineations of this type examined by the author were very stony and were thus so described and rated. Table 6 provides a complete description of the variables used in LASTAN.

TABLE 6

Variables, classes, and descriptions used in the soil suitability analysis

| VARIABLE | CLASS | DESCRIPTION | |
|---|---|---|---|
| SPH | 01 | 5.4 | Very strongly acid |
| | 02 | 5.4-5.8 | Strongly acid |
| | 03 | 5.9-6.5 | Slightly acid |
| | 04 | 6.6-7.2 | Neutral |
| | 05 | 7.2 | Alkaline |
| TEX | 01 | Fine sand | |
| | 02 | Sandy loam | |
| | 03 | Loam | |
| | 04 | Clay loam | |
| | 05 | Clay | |
| | 06 | Organic | |
| DEP | 01 | 0.3-0.8 (m) | Very shallow |
| | 02 | 0.9-1.4 | Shallow |
| | 03 | 1.5-2.0 | Moderately deep |
| | 04 | 2.1-2.6 | Deep |
| | 05 | 2.6 | Very deep |
| DRA | 01 | Excessive (droughty) | |
| | 02 | Good | |
| | 03 | Imperfect | |
| | 04 | Poor | |
| | 05 | Very poor | |
| SLO | 01 | 0.0-2.0 (%) | Level-very gently sloping |
| | 02 | 2.5-4.0 | Gently sloping |
| | 03 | 4.5-8.0 | Moderately sloping |
| | 04 | 8.5-16.0 | Strongly sloping |
| | 05 | 16.5-32.0 | Steeply sloping |
| | 06 | 32.0 | Very steeply sloping |
| STO | 01 | No stones | |
| | 02 | Few stones | (Slight mgmt. probs.) |
| | 03 | Many stones | (Strong mgmt. probs.) |
| | 04 | Excessively stony | (Impedes cultivation) |
| PPP | 01 | 0-9 (ppm) | |
| | 02 | 10-20 | |
| | 03 | 21-25 | |
| | 04 | 26-30 | |
| | 05 | 31-60 | |
| | 06 | 61-80 | |
| | 07 | 80 | |
| KKK | 01 | 0-60 (ppm) | |
| | 02 | 61-80 | |
| | 03 | 81-120 | |
| | 04 | 121-180 | |
| | 05 | 181-250 | |
| | 06 | 250 | |

### 3.3.3 Site description, m[S]m

The basic unit of interpretation was the map delineation, as defined in Chapter 1. There were a total of 145 different map delineations or site types within the study zone. Several of these types reoccurred more than once within the boundaries of the area.

Representation and description of these sites in a form acceptable to LASTAN was accomplished by creating a 145[S]44 site matrix of the type described in Section 3.2 above. Each row represented a specific map delineation and each column defined one of the variable states described in Table 6, above. The completed matrix may be found in Appendix G.

### 3.3.4 Soil factor ratings and interactions, m[U]m

The first step in the construction of a m[U]m matrix for crop group A was the development of a rating system which would be used to fill the diagonals. Since there existed an average of approximately five classes per variable it was decided to set up a five-class rating system, shown below in Table 7.

The actual assignment of rating points to the diagonal was made using information contained in the bibliography cited in Appendix A in conjunction with interviews held with Agreps at O.M.A.F., Bells Corners, Ontario; and crop specialists at Kemptville College of Agricultural Technology, Kemptville, Ontario.

TABLE 7

The rating system used within the diagonal of m[U]m

| RATING | DESCRIPTION |
|---|---|
| 5 | EXCELLENT: this state represents ideal growing conditions for this crop group assuming that the states of all other variables are optimum and constant. The only interactions generated by this state will be positive although it may be downgraded by the occurance of unfavorable states of other variables in conjunction with it. |
| 4 | GOOD: this state represents slightly suboptimum growing conditions. If the crop is grown without corrective measures then crop growth will be slightly lower than under variable states rated 5. Other variable states may generate both positive or negative interactions which would modify the effects of this state on overall suitability. |
| 3 | MEDIOCRE: this state represents suboptimum conditions. Crop growth will normally be poorer than on sites where the particular variable is rated 4 or 5. However in some cases soil factor interactions may serve to upgrade or downgrade the effects of this state on overall suitability. |
| 2 | POOR: the conditions represented by this variable state are marginal to unsuited for this crop group even with other conditions optimum. The feasibility of corrective measures is slight even under high management. This state will generate negative interactions but may itself be upgraded in exceptional conditions by other strongly influencing variable states. |
| 1 | UNSUITED: the conditions of this variable state are definitely unsuited to this crop group. Corrective measures are unfeasible under assumed management. Negative interactions generated by this state (as a strongly limiting factor) are likely to be significant. |

Filling the interaction submatrices, on the other hand, was understandably more complex. Before any progress could be made in this regard the theoretical nature of interactions had to be examined and ways of "measuring" them established.

Defined above in section 3.2.2, two "types" of interactions were identified. Type one interactions were labeled "systematic" or "across-the-board" by nature of their effect upon the overall suitability of a map delineation for a use. These effects exist irrespective of the other variable states present at the site in question. Inherent interactions occur when it is known that a state of one variable either eliminates all positive effects, or theoretically at least, boosts all low ratings, generated by the other variable states in the system.

Variables generating inherent interactions are always those which cannot be corrected within the confines of the assumed level of management. They include stoniness (classes 3 and 4), reaction (class 1), slope (classes 5 and 6), depth (classes 1 and 2), drainage (class 1), and texture (all classes).

In general, type one interactions are the easiest to recognize and evaluate. Most parametric methods of deriving soil suitability, such as those described by DUBOIS, (1972); and others already mentioned, account, in a general way, for some of them.

Type two, "conditional" interactions were more subtle and hence more difficult to recognize and measure. These occur when certain variable states, by nature of their edaphic influences, actually modify the effects of specific states in other variables upon plant growth and hence upon yield output. For example, the governing effect of soil moisture variations upon nutrient uptake by plants in soils possessing ample nutrient supplies aptly shows a type two interaction in operation.

Whereas in practice type one interactions were usually found to be negative, type two interactions are often synergistic as well as limiting. An example of a positive conditional interaction would be the beneficial effects of high lime conditions on nutrient availability and structure in sandy-textured soils. Alternatively, the positive effect of good drainage upon nutrient uptake by plant roots which, in turn, affects plant growth is another example of a type two interaction.

Once defined, these relationships had then to be identified and measured. Identification became a matter of reviewing the bibliography of crop requirements contained in Appendix A and searching out additional pertinent literature. A bibliography of this additional material may be found in Appendix B. It should be carefully noted that much of this literature describes soil factor interactions only in ordinal terms. Conclusions and universal relationships may be viewed as, at best, expressions of expert opinion. Field trials and quantitative measurements are few and, in this author's opinion, not always universally applicable. Thus, the numerical expression of the qualitatively described relationships should be accepted, at this stage of development, in ordinal terms only.

Measurement of a pairwise interaction depended on its type (systematic or conditional) and its strength (within the assumed level of management). Inherent interactions were usually measured by subtracting the rating of the variable state causing the interaction from that state receiving the interactive effect. This difference multiplied by -1 became a measure of the interaction existing between the two states and was placed in the appropriate cell of 44[U]44. Adjustments were made where these values appeared either too low or too high.

Type two interactions were also measured somewhat arbitrarily. A scale was constructed which ranged from +2 to +10. It was then divided into five classes as shown in Table 8 below. Where a conditional interaction was known to occur, the diagonal ratings for each variable state were added together. If the resultant sum fell into a class which, due to the interaction, did not conform to the estimated site suitability for crop group A then an adjustment was made. This adjustment took the form of a positive or negative number which, when added to the sum of the two variable state ratings, gave a result conforming to the estimated site quality for crop group A. This number was considered a crude measure of the type two interaction and was placed in the appropriate cell of the submatrix defined by the two interacting soil variables.

TABLE 8

Ratings established to assess the importance of type two interactions

| RATING | CLASS | DESCRIPTION |
|---|---|---|
| >10 | 5 | Excellent |
| 9<br>8 | 4 | Good |
| 7<br>6 | 3 | Mediocre |
| 5<br>4 | 2 | Poor |
| 3<br>2 | 1 | Unsuited |

The m[U]m has been reproduced in Appendix G, below.

Once both components, n[S]m and m[U]m were complete a final task was to enter them as input data into the LASTAN program which performed the actual calculations.

## 3.4 SYNTHESIS

The goal of this chapter has been to describe how LASTAN calculates its indices of soil suitability for an agricultural crop group. First the theoretically desirable characteristics of a soil suitability methodology were examined. Next, subsections 3.2.2 to 3.2.4 show, both mathematically and by means of an example, how theory was operationalized into a model. The last part of the chapter dealt with the data used to implement the model. The suitability indices generated by LASTAN were, to say the least, very encouraging. Chapter 4 below has been reserved for a discussion of them.

## Chapter IV

## RESULTS

### 4.1 GENERAL COMMENTS

The suitability ratings generated by LASTAN took values ranging between -2 and +59. Fifty-six per cent of the sites had values greater than +40. Thirty four per cent of all sites fell between +20 and +40. The remaining 20 per cent lay below index values of +20.

Those sites rating highest (with values greater than +46) had the following general properties:

1. Surface pH varied widely from class 2 (pH = 5.4 - 5.8) to class 5 (pH > 7.2) with the majority of sites falling in classes 3 or 4 (pH = 5.9 - 7.2). This broad range of acidities, in highly rated sites, is more a reflection of management assumptions than wide preferences on the part of crop group A (see group requirements in Appendix E). With lime applications forming an integral part of management practices in eastern Ontario, corrections of soil acidity on most soils are relatively easily and inexpensively made, (PARKS, 1955, p.12-13; ATKINSON, 1964, p.3-7; MILLER, 1978, pers. comm.).

2. Highly rated soils were mostly sandy-loams, loams, plus a few well-drained clay-loams. Drainage classes ranged from good to imperfect. All sites exceeded 0.9 metres depth and most were 1.5 metres or deeper. Stoniness and slope were never serious problems.

3. Nutrient contents, like pH, also varied considerably for highly rated soils. Most were relatively low in phosphorus, a trait common to many of the lighter textured soils in Carleton County, (HILLS & RICHARDS, 1944, p.96-100). Potassium levels, however, ranged from low to high, most sites possessing 80 ppm. and higher within the upper 14 cm. Since fertilization was incorporated into the assumed management practices, low nutrient content was not seen as a severely limiting factor except in notably infertile sands. However, soils naturally high in P and K did rate higher on these factors than those with low concentrations of these elements.

In general, LASTAN rated highest, or most suitable to crop group A, those soils which were slightly acid to neutral, moderately deep, well but not excessively drained loams which were relatively stone-free, flat, and possessed moderate reserves of phosphorus and potassium.

Those ten sites rating lowest (with values less than or equal to 13) are outlined as follows:

1. Surface acidity, slope, and nutrient content were never found to be major limiting factors. Soil pH values range from class 3 (pH = 5.9 - 6.5) to class 5 (pH > 7.2) over a flat to moderately sloping topography. Nutrient levels were similar to those sites rated favorably.

2. Textures were generally characterized by sandy-loams and loams. Four sites, however, were organic, and were thus limited by this fact.

3. Drainage was a major problem only on the four sites overlain by organic deposits.

4. By far the most severely limiting factors for the poorly-rated soils were depth and stoniness. All, with the exception of sites 144 and 145 (U14.0), were no deeper than 0.9 meters and were very to excessively stony.

The poorer soils, viewed collectively, did not all have the same general characteristics. They were limited by many different factors.

Those sites with intermediate ratings (ie. with indices falling between 14 and 46) had the following characteristics:

1. All sites possessed pH values greater than 5.4. Available K levels were surprisingly high (most sites possessed between 61 and 120 ppm.). Available P was low in most cases.

2. Slope was restricting in only one case and shallow soils limited moderately-rated sites only twice.

3. The most serious limiting factor was drainage, which was poor in thirty-four of these seventy-nine sites. Excessively sandy-textures and severe stoniness were a problem in twenty-seven cases.

Further examination of the results reveals that drainage was overwhelmingly the most common limiting factor in the study area. It surfaces in 50 (34%) out of the 145 sites assessed. Stoniness and texture follow close behind. The former was singled out in 36 (25%) cases as a major hinderance whereas the latter (sands and occasionally organics) is limiting in 29 (20%) sites. Very shallow soils were found in 12 (8%) of all sites and slope was a problem only in one case. Overall, 95 (65%) of the map delineations possessed at least one major limiting factor. Two or more factors were limiting in 30 (45%) of these 95. Thirty-five per cent (50) of all sites were completely free of major limitations. However not all of these rated highly. It was common to find soils indexed as low as 40 which had no single severe limiting factor. In such cases combinations of several slightly or moderately limiting factors, in interaction with each other, and not singled out by the limiting factor algorithm, would combine together to reduce the rating of the site. See Figure 12 for a sample and Appendix H for the complete output generated by LASTAN.

| NO | IDENTIFICATION | S INDEX | S CLASS | LIM. FACTORS | CAP. CLASS |
|---|---|---|---|---|---|
| 29 | F5.P/3.2 | 5.0 | 7 | DEP STO | 7R*P*Wv |
| 30 | G1/2.2 | 52.0 | 1 | | 1p |
| 31 | G1/2.3 | 50.0 | 2 | | 2pt |
| 32 | G1/2/3.2 | 53.0 | 1 | | 1p |
| 33 | G1.S/2.2 | 29.0 | 4 | DEP | 3RP |
| 34 | G1.P/2.3 | 36.0 | 3 | STO | 3Rpt |
| 35 | G1/2/3.3 | 51.0 | 1 | | 2pt |
| 36 | G1/2.2/3 | 46.0 | 2 | | 1p |
| 37 | G1/2.4 | 49.0 | 2 | | 2Tp |
| 38 | G1/2.3/4 | 49.0 | 2 | | 2pt |
| 39 | G1.SP/2.4 | 22.0 | 5 | STO | 5P*RT |

Figure 12: LASTAN suitability indices and major limiting factors including suitability and capability classes

## 4.2 RELIABILITY OF THE MODEL

While a general discussion of the results provides a notion of their quality, a more accurate measure of their worth is a test of significance. In this case the ideal, if not unwieldy, check would be to correlate known long-term yields of crop group A under specified management conditions versus the suitability indices themselves. Unfortunately such an exercise was impossible to undertake because of the difficulty involved and time required to obtain the necessary yield data.

The capability classes of each map delineation, prepared by MARSHALL et al, (1976) for Nepean and Gloucester Townships were used as a substitute. MARSHALL's classification is a refined version of "the system used in the Canada Land Inventory and developed by the Canada Soil Survey Committee", (MARSHALL et al, 1979, p.117).

Studies by HOFFMAN, (1973,1971); ANDERSON, (1971); NOBLE, (1967); and more recently by PATTERSON, (1978); and PATTERSON & MACKINTOSH, (1976) indicate that C.L.I. capability classes in Ontario are closely related to both yields and economic returns to farmers. On the strength of these authors' respective findings the refined capability system was accepted as a reasonably accurate reflection of the agricultural potential of the study area for field crops.

Although some argue that there exist very slight differences in the definitions of <u>capability</u> and <u>suitability</u> (see Chapter 1), these have not been found to be significant, (BRINKMAN & SMYTH, 1973, p.101; VINK, 1975, p.237) Furthermore, any conceptual discrepancies become irrelevant for comparative purposes when:

1. both systems are qualitative and deal with the same land-use(s), (F.A.O., 1976, p.2[illegible]).

2. comparisons are restricted to a defined spatial area, (DUMANSKI, 1979, pers. comm.).

In this study these two conditions are met. Thus, soils with high suitability should rate highly in terms of capability for the same land-use. This same relationship should also apply to soils with medium and low potential. The degree of association existing between MARSHALL's capability system and LASTAN's suitability indices can therefore be interpreted, within the study area, to be an approximate measure of the accuracy or worth of the LASTAN model.

4.2.1 Anomalies

In several cases (particularly within capability classes 3, 4, and 5) anomalies exist between capability classes and LASTAN ratings. For example, two map delineations rated class 4 are given very high index values (56 and 58 respectively). Other sites rated low by the latter fall into capability classes 2 to 3.

These dissident sites (there were 31 in all) were identified and examined. Four major reasons were found to explain their singular behavior:

1. Eleven of the thirty-one anomalies occurred as the result of data discrepancies. In these cases field data on pH, nutrient availability, and, in one case, drainage, used by LASTAN, did not correspond to site conditions used by the capability study. LASTAN usually rated such sites more favorably than did the capability classification.

   These discrepancies were seen to have occurred because of scale differences in the two studies. The capability map spanned all of Nepean-Gloucester. Its ratings were based upon soil map data, broadly representative of this entire region. The present study was more localized and site-specific. The majority of type one anomalies involved factors as variable as pH and nutrient content. Such differences are not surprising and certainly pose no threat to the validity of the LASTAN model.

2. Another group of anomalies (six in all) resulted because a soil structure variable, included by the capability class system, was not incorporated into LASTAN. This meant that negative interactions created by poor structure were not accounted for by the latter. Hence, LASTAN rated these sites higher than the capability classification. Again, such discrepancies reflect more upon differences in data than on the capabilities of the methodologies. They do however, serve to single out an important weakness in LASTAN data which should be rectified in any subsequent study.

3. The map delineation G5/2.2 proved to be a problem. The capability system rated it 3Wvp (Wvp = variable imperfect drainage coupled with slight stoniness problems) while LASTAN gave it a very high rating of 55 with no major limiting factors. No satisfactory explanation was found to account for such strong differences in treatment by the two systems. It represents a random peculiarity in the methodology which requires further study.

4. The most common anomaly occurred due to the importance LASTAN places upon negative interactions generated by severely stony and shallow soils. The phase "p" used

on the soil map referred to "...very stony to exceedingly stony land [whose] surface stone content [is] sufficient to impede tillage...", (SOIL RESEARCH INSTITUTE, 1976). The "S" phase was used on sites with "...50 to 100 cm. of mineral soils overlying bedrock...", (SOIL RESEARCH INSTITUTE, 1976).

LASTAN rated these conditions much more severely than did the capability classification. This was due in part to slight differences in objectives in the two studies. LASTAN was concerned with a specific subset of field crops whereas MARSHALL et al's ratings included pasture and forage crops. The latter two generally require significantly less field preparation and hence are frequently better suited to marginal land than their more intensively cultivated counterparts.

4.2.2 Tests of Association

It is evident that the causes of anomalies (with perhaps one exception) are related to such factors as data interpretation, and slight differences in objectives between the two systems. They do not appear related to faults or bugs in the operating characteristics of LASTAN itself. Therefore, in testing the degree of association which exists between capability class and suitability indices it did not appear unreasonable to drop these anomalies (with the exception of site G5/2.2 whose excentricities

Figure 13: Capability classes versus raw suitability indices (unclassed) in SE. Nepean

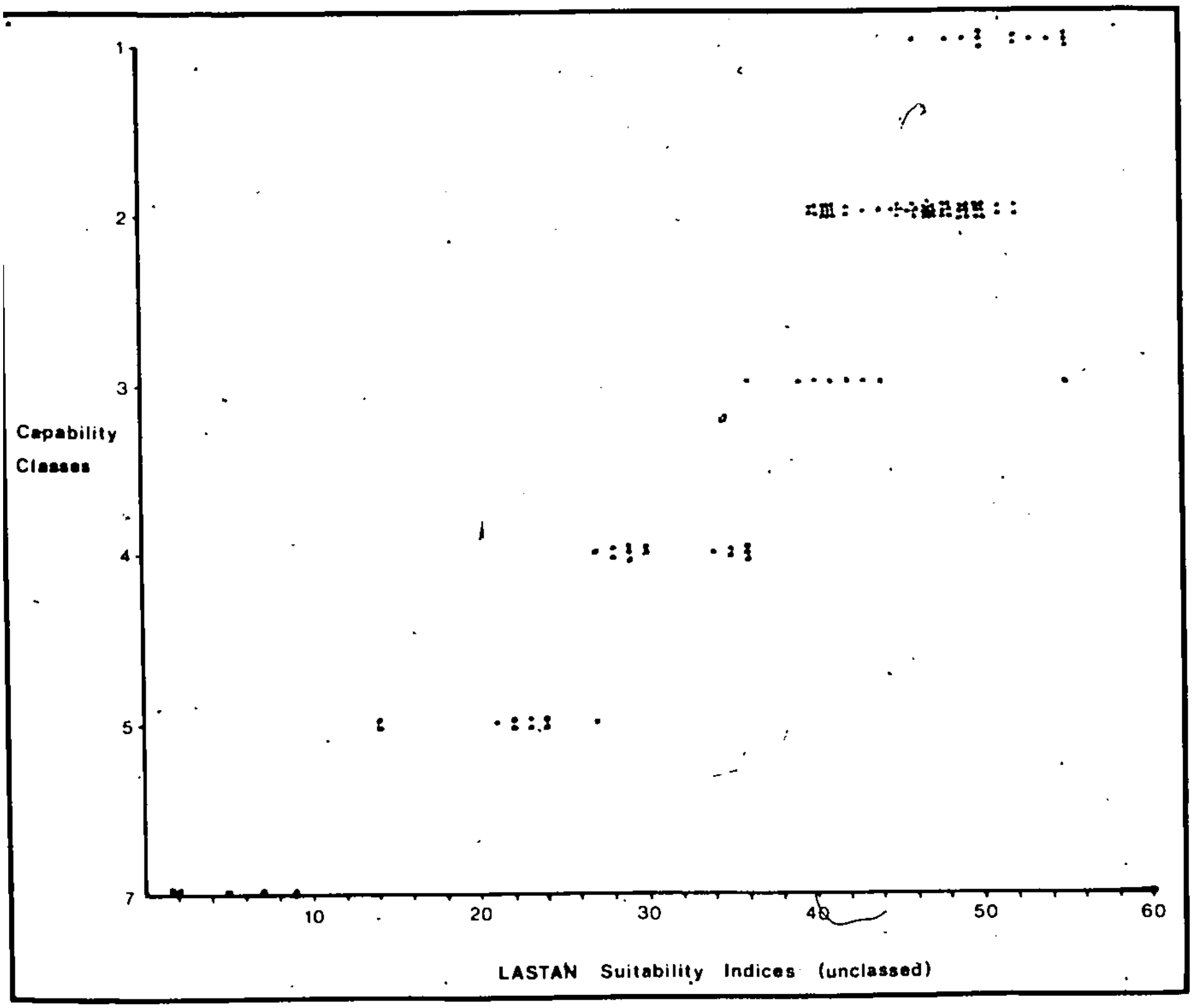
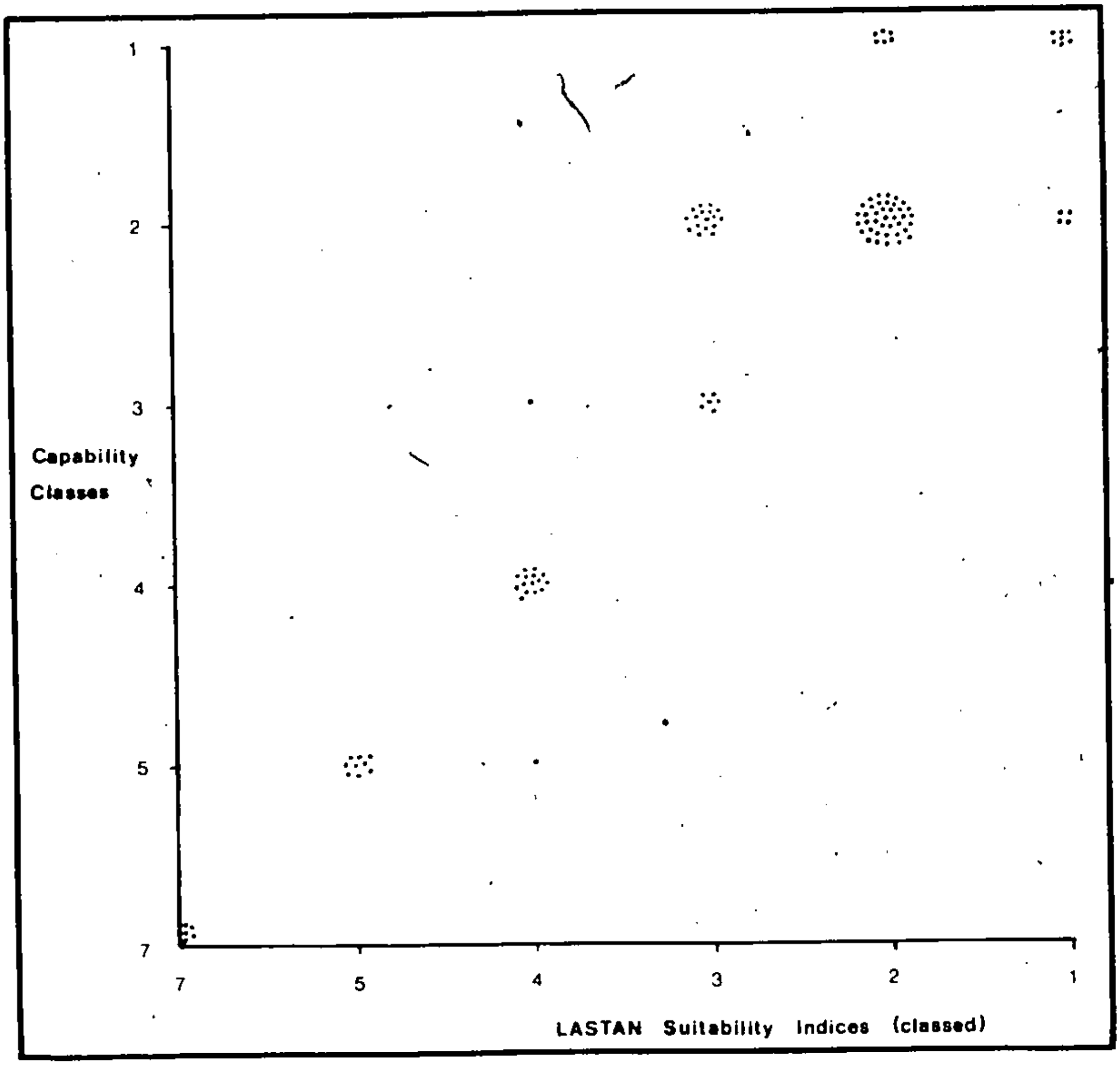


Figure 14: Capability classes versus raw suitability indices (classed) in SE. Nepean



could NOT be reasonably accounted for) The four organic map delineations were also omitted because the capability study had not rated them. A total of 109 sites remained.

Four statistics, three of which were specifically designed to measure association, or correlation, between ordinal sets of data, were employed. These were Kendall's "tau-C", Goodman and Kruskal's "gamma", and Somer's "D"[14]. Information theory's I.M. statistic was used to verify and explain the significance of some of these results[15].

4.2.2.1 Raw indices versus capability

Data were processed in four ways. First, the association between raw suitability indices and capability classes was assessed. The upper left portion of Table 9 depicts the results.[16] Somer's D (symmetric) and tau-C take values of 0.728 and 0.703 respectively. Gamma supports them with a very high 0.902. Such values are indicative of a strong relationship between suitability index and capability class. Somer's D asymmetric coeffi-

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[14]GARSON, (1971, pp.158-162) provides a good discussion of the relationship between these three statistics. For those unfamiliar with them, each approaches a value of +1 under perfect monotonic correlation and 0 when no relationship exists. Gamma can also equal +1 in cases where monotonic correlation does NOT exist. Both tau-C and gamma are symmetric while Somer's D may be expressed as either a directional or asymmetric test.

[15]I.M. = Mutual Information

[16]Computed using SPSS sub-routine "Crosstabs" in NIE et al, (1975, pp.218-245) except for I.M. which was calculated by hand from contingency tables derived by the above.

cients are 0.887 with suitability dependant and 0.617 with capability dependant. These figures suggest that suitability indices are distributed about a narrower number of capability classes than the reverse. This is not surprising since there are only six capability classes but fifty-eight possible suitability indices.

In essence then a major goal of this research has been met. The statistical results of Table 9 show that it is possible to reproduce, in a systematic mathematical way, the processes involved in the qualitative rating of current land suitability for field crops. The implications of these results to future research are expanded upon in Chapter 5 below.

4.2.2.2 Classed indices versus capability

Next, in order to comply with the soil suitability framework established by BRINKMAN & SMYTH, (1973, p.40-43); F.A.O., (1976, p.17-23); and VINK, (1975, p.280-287), and to make output more manageable from a user's point of view, LASTAN indices were grouped into suitability classes. Information theory was used to prevent any bias from entering into the system during the classification procedure. This was accomplished by ensuring that the classes of LASTAN indices had the same frequency distribution across the 109 map delineations as the capability classes. The capability system had 18 Class 1, 59 Class 2, 8 Class 3, 14 Class 4, 10 Class 5, and 5 Class 7 soils. LASTAN's classification was made by ensuring that its Class 1 contained those 18 map delinea-

TABLE 9

Summary of statistical tests of association between capability classes and suitability indices

| STATISTIC | CAPABILITY CLASSES vs RAW INDICES W/ INTERACTIONS* | CAPABILITY CLASSES vs RAW INDICES W/OUT INTERACTIONS* |
|---|---|---|
| tau-C | +0.70358 signif.=0.0000 | +0.58743 signif.=0.0000 |
| gamma | 0.90210 | 0.80243 |
| D | 0.61733 w/ capability dependant | 0.56052 |
| | 0.88784 w/ suitability dependant | 0.74127 |
| | 0.72828 symmetric | 0.63835 |
| **STATISTIC** | **CAPABILITY CLASSES vs SUITABILITY CLASSES W/ INTERACTIONS** | **CAPABILITY CLASSES vs SUITABILITY CLASSES W/OUT INTERACTIONS** |
| tau-C | 0.62702 signif.=0.0000 | 0.55773 signif.=0.0000 |
| gamma | 0.93890 | 0.88295 |
| D | 0.80981 w/ capability dependant | 0.70165 |
| | 0.79123 w/ suitability dependant | 0.70380 |
| | 0.80041 symmetric | 0.70272 |
| I.M. | 0.8610 | 0.7170 |

* values multiplied by -1 to eliminate negative signs

tions rated highest, its Class 2 contained the next 59 most highly rated sites, and so on.

The assumption implied here is that if LASTAN and capability were perfectly correlated then:

1. the number of map delineations (within the study area) in each class would be identical for both systems, and

2. each map delineation would fall into the equivalent class of both systems.

In other words, both the amount or quantity of information (1, above) and the actual information itself (2, above) would match in both systems. By ensuring that the first condition is met, the second can then be tested with the assurance that no bias or forcing of association has been introduced by the act of classification.

The lower left portion of Table 9 shows the statistical measures of correlation between classed LASTAN indices and capability classes. Tau-C has dropped slightly whereas both gamma and Somer's D symmetric have risen. Somer's D asymmetrics are now very nearly equal (0.809 & 0.791) since the number of classes in both systems is now identical.

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[17]I.M., the Mutual Information statistic is calculated from contingency tables by the equation:

$$I.M. = 1/N \left[ N\log N - \sum_{i=1}^{m}\sum_{j=1}^{m} f_{ij}\log f_{ij} - \sum_{i=1}^{m} f_{i.}\log f_{i.} - \sum_{i=1}^{m} f_{.j}\log f_{.j} \right]$$

The additional test of association, I.M.[17], was employed as a final check on the results. Here it takes a value of 0.861. Since capability classes were used as a generally acceptable reflection of true soil potential for field crops, the I.M. value suggests that the amount of uncertainty involved in correctly predicting capability classes at a site is reduced by 86.1 per cent when the LASTAN indices are known. Table 10, below, is a description of these classes.

It should be noted that the descriptive interpretation of these classes is based both upon the variables with which they were derived and the actual soil conditions found within the study area. Had other variables been used or sites with strongly different characteristics been assessed then these descriptions would change slightly. The principal area of modification would lie in the types and strengths of limiting factors affecting the rating system.

4.2.2.3 LASTAN without interactions versus capability

Given the results obtained above the author then tested the hypothesis that the incorporation of interactions does indeed improve the predictive capacity of the model. All entries below and above the main diagonal of matrix 44[U]44 (see Chapter 3)

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This statistic shows the amount of shared information in two systems, each possessing equal total quantities of information. It approaches +1 as the two systems approach equality.

were given values of 0. This modified, "interactionless" 44[U]44 was then input into LASTAN and indices calculated. Tests of association (see right side of Table 9) between these indices and capability suggest that LASTAN's predictive capacity drops by at least 10 per cent when interactions are ignored. A comparison of I.M. statistics shows that the amount of common information shared by the two systems increases by some 14.4 per cent when interactions are incorporated.

| SUITABILITY CLASS | DEFINITION |
|---|---|
| 1 | -All soils with indices greater than 50. These soils meet virtually all requirements for production of crop group A. In general they are deep, well to imperfectly-drained sandy loams and loams. Topography, stoniness are never limiting and pH, in most cases fluctuates between 5.9 and 7.2. These soils, under equilibrium conditions, possess at least moderate reserves of potassium or respond well to additions of phosphorus and potassium. Suitability class 1 sites are well to ideally suited to field crop production. Output in yields would be expected to exceed inputs of labour, time, and capital. |
| 2 | -All soils with indices between 41 and 50 inclusive. These soils meet most of the requirements for field crop production. In general they are deep, moderately well or at least imperfectly-drained loams and clay loams. They may be somewhat limited by a number of factor combinations including drainage, slight stoniness, rolling topography, small textural problems or slight nutrient deficiencies, and acidity. Class 2 soils respond favorably to additions of lime and fertilizer. Outputs are expected to exceed inputs because these sites are well suited to crop group A, but yields will be lower than on Class 1 land receiving the same level of management. |
| 3 | -All soils with indices between 36 and 40 inclusive. These soils are only moderately suited to the production of crop group A although they may be well suited to other kinds of crops. In general they are deep and not adversely affected by topography. Drainage, texture, pH, stoniness, and poor nutrient status are common limiting factors. They may be present in isolation as severely limiting factors or in combination as collectively limiting factors. Class 3 soils may be physically improved. However, the desirability of improvement will depend on economic factors as well as the supply and demand of other kinds of land in the region in which they occur. |
| 4 | -All soils with indices between 27 and 35 in- |

| | |
|---|---|
| | clusive. These soils are marginally suited to the production of crop group A and are strongly limited by factors such as poor texture, poor or excessive drainage, stoniness, or topography in isolation or in combination. Limiting factors are difficult to correct due to interactions with other factors or because of the nature and severity of the limitations themselves. Only in areas poorly endowed with better soils should Class 4 sites be put into production of group A crops and then only when market factors are favorable. |
| 5 | -All indices between 12 and 26 inclusive. These soils are poorly suited to crop group A due to the severity of limiting factors such as excessive stoniness, very poor drainage, adverse topography or shallowness. Yield outputs are expected to be marginal under the assumed level of management. |
| 7* | -All indices below 11. These soils are not suited to the production of crop group A. Depth to bedrock is commonly the most severe limiting factor. Stoniness, very poor drainage and steeply sloping topography also hinder production in many cases. |

* this is actually the 6th class. It was called class 7 in order to comply with the enumeration of the capability system to which it was compared.

TABLE 10

A description of suitability classes

## 4.3 SYNTHESIS

The purpose of this chapter has been to describe and test the output generated by the LASTAN suitability model.

Those sites rated highest by LASTAN all had common characteristics whereas sites rating moderately and poorly were more heterogeneous in nature, being afflicted by several possible combinations of limiting factors.

Indices for each site were manipulated into 4 forms: raw indices, classed indices, raw indices without interactions, and classed indices without interactions. Each of these four forms was tested against the capability classes for the same sites. A high degree of correlation was found between both raw and classed indices versus capability when the former two incorporated soil factor interactions. Such an association dropped appreciably when interactions were ignored.

These results indicate that integrated-parametric type approaches to soil survey interpretation which embody a systems or interactive structure definitely have a use potential within the field of land evaluation. Additional implications are discussed more fully in Chapter 5.

# Chapter V

# CONCLUSIONS

"But that is research: more questions than answers....the candle taken out further into the darkness merely illumined a greater darkness." (RENNIE, 1974, p. 180)

## 5.1 REITERATION

This thesis is composed of three interrelated phases of research which provide a framework for determining soil suitability for different land-uses under a variety of soil conditions.

The first phase provides the principal thrust of the research. This is the design of a methodological framework which embodies, among others, two fundamental characteristics:

1. It recognizes that each use type considered possesses specific soil or land requirements which may differ from the requirements of other use types. It accommodates these differences in its calculations of soil suitability indices for each unique use type. These types may reflect broad typologies (such as agricultural use and urban use) or, as was the case here, detailed divisions within one of these sectors.

2. It recognizes that the contribution a soil factor makes to the suitability of a site for a specific use is not constant but may vary depending upon the conditions of other factors at that site. These variations or interactions are easily accommodated by the LASTAN model.

This flexibility appears to make it well suited to a variety of soil and land interpretations. It also solves some of the problems inherent in other methods of soil suitability assessment, as as discussed in Section 1.2. The way in which the method embodies these features is discussed in Section 3.2.

The second research phase involved putting LASTAN into operation. This required both site and use data. The choice of a pilot study area was made expedient by the existence of a detailed data base: the recently published soil map and report for Nepean-Gloucester Townships in Carleton County. A portion of this sheet, representing 7050 hactares in southeast Nepean, was chosen for reasons given in Section 1.3.

Selecting land-use types was somewhat more complex. The idea of employing crop groups for this purpose was based upon practical grounds. Elaborated in Chapter 2, the application of numerical taxonomy to a set of individual crops allowed the author to identify these groups. The members of each group were expected to perform similarly under most sets of specified soil conditions. One of these groups, the field crops, was selected as the land-use type to be used in putting LASTAN to work.

The ordinal rating of relevent soil properties and their interactions for field crops was made from a review of the literature on crop physiology, crop edaphics, and soil property interactions cited in Appendix B.

The third phase was an evaluation of the suitability indices generated by LASTAN. These indices, in their raw form, and agglomerated into suitability classes correlated well with the capability classes derived by MARSHALL et al, (1979), for field crops in the same area.

Despite the fact that the model was put into operation and its results tested, the overall scenario of the project has been essentially experimental. Further testing at differing scales and with different uses employing more accurate data bases is recommended before other applications should be envisaged.

## 5.2 PROBLEMS

VINK, (1975, p.149), in a discussion of landscape ecology, has observed that:

> "Specific information on soil requirements of crops is often vague partly because crop specialists often tend to neglect studying the soils and soil scientists tend to neglect studying the crops. Soils information in crop handbooks is therefore often vague, and in books on soil science information on crops is often completely lacking."

This statement applies here particularly with regard to certain difficulties in aquiring information on conditional interactions, general soil requirements, and yields of field crops within the pilot study area. The influence of these data problems upon the outcome of this project was manifest in three ways.

First, completing the crop raw data matrix and a single 44[U]44 took more time than expected. This meant that a testing of LASTAN was limited to only one crop group and that LASTAN's potential to account for several land-use types could not be demonstrated. Such a problem is not severe. Had more time and manpower been available to the author these difficulties could easily have been overcome.

Second, that data which was available was of such variable quality that only nominal and ordinal measurement scales could be used in the construction of 145[S]44 and 44[U]44. Thus it would seem that the predictive capabilities of LASTAN were not as precise as if interval or ratio input data had been used.

Third, the ideal evaluation of LASTAN's results would have been a correlation of generated suitability indices with yield data for each map delineation. Because such data was unavailable correlation tests with capability classes in the same area were substituted.

## 5.3 FUTURE RESEARCH POSSIBILITIES

By accepting the feasibility of employing LASTAN, three general directions open themselves to questions of future research.

### 5.3.1 Data

Without wishing to belabour the point, there remains a pressing need for experimentation leading to the compilation of data banks on crop response to varying soil conditions. Already some work has been done in this field. The success of the SIMFOY growth simulation model of SELIRIO & BROWN, (1978), for forages is based upon detailed knowledge of these crops' moisture requirements at varying stages of growth. In addition, work on other soil-generated crop stresses has been compiled by F.A.O., (1976). This latter study examines (among other things) the relationship between salinity and crop growth. Several symposiums during the 1960's and early 1970's, such as those edited by JACKS, (1967), and HILLEL, (1972), also concentrated on plant response to changing environmental conditions. Nonetheless, more information is needed, particularly with regard to those factors such as stoniness, soil structure, and slope orientation.

More data is also needed on soil property interactions. It must be specific. It must relate to individual crops or crop groups as opposed to "plants" in general. The bibliographic Appendix B shows evidence of research in the field. However the skills of soils and crop specialists and ecologists must be united in an inter-diciplinary framework, bound by specific goals, objectives, and defined formats of data representation and storage before real progress can be made in this regard.

### 5.3.2 Model Modifications

Another avenue of future research lies in extending the breadth or power of LASTAN itself. Three possibilities immediately come to mind, each of which would mean changing the study scale.

The first of these involves removing the assumption of climatic invarience (see Section 1.2.6) and replacing it with climatic variables which could be incorporated into the model. Here the n[S]m site matrix would receive additional columns, each column, of course, corresponding to a variable state of a climatic variable. The m[U]m array would also change. Columns and rows would be appended. The additional diagonal entries would take the form of climatic ratings whereas those new entries below the diagonal would correspond to climate-soil interactions.

The data used to express these ratings and interactions could be reflections of detailed and quantitative knowledge or it could be of a general, more subjective nature. Either way, this addition to LASTAN would permit its use over broader areas where climatic variation exists. It would also allow more intensive studies to be made in smaller regions by accounting for variations in micro climate caused by, say, slope orientation, elevation, or frost pocket depressions. In addition, the inclusion of cumulative degree-days or corn heat units as climatic variables would permit the incorporation of interactions between these variables and soil texture and soil water. Texture and soil moisture content heavily influence a soil's thermal regime especially in spring. These interactions are viewed as critical in more northern latitudes where length of growing season is commonly a limiting factor to some kinds of agricultural production.

One of the biggest problems of site-factor methods has been a difficulty in explaining and measuring the importance of variations in soil variables over space. The importance of soil properties and their interactions to crop growth, within a defined spatial area, where management and rural infrastructure are uniform, could be considered constant for a single use type. However, as one moves over space, socio-economic conditions can change even though management levels remain constant. These changes can take place within recurring soil mapping units, (i.e. physically and even climatically homogeneous delineations). As these regional, non-soil factors vary the importance of the soil variables will also vary, not edaphically but in terms of their overall importance to soil suitability.

The second conceived direction of future research would involve the incorporation of at least some of these socio-economic variables into the model in an interactive way. This would change the ratings produced, from soil suitability indices to ratings of <u>land</u> suitability. To illustrate how this might occur, consider a simple example. Assume the existence of two regions "A" and "B", each containing two soil mapping units "1" and "2". These soils, for convenience sake, are only distinguished by differences in pH: soil 1 is neutral while soil 2 is strongly acidic. Now, in region A, crushed lime is readily available from nearby quarries and costs per ton are low. In region B, however, lime must be trucked in from region A and thus costs per ton are appreciably higher. With this scenario in mind assume furthermore that the land-use type "X" being considered is one which requires neutral soils, (see Figure 15).

The example along with results of a land suitability analysis, performed by LASTAN, are displayed in Figure 16, below. As one can see, map units 1A and 1B differ only with regard to the cost of lime in each area. The same is true for sites 2A and 2B. Since the land-use type X prefers neutral soils, this condition is rated highly (5) in 4[U]4. The acid condition is rated low (1). Also notice that the diagonal entries under "lime" in 4[U]4 are not rated. This occurs because although the cost of lime influences land suitability, it does so only insofar as it moderates or enhances the importance of pH. Thus lime costs are interactive in their influence and lend no weight to the suitability rating in isolation.

The results of this little example are shown in 4[Cs]1 of Figure 16. Site 1A and 1B both have high land suitability ratings because the availability of lime does not influence their neutral characters. Site 2A and 2B, both acidic, have different ratings. Site 2A is moderately high (4) due to the ease and low cost of correcting its acidic defficiency. Site 2B, however, is

Figure 15: Stylized map of two economic regions, each containing two mapping units

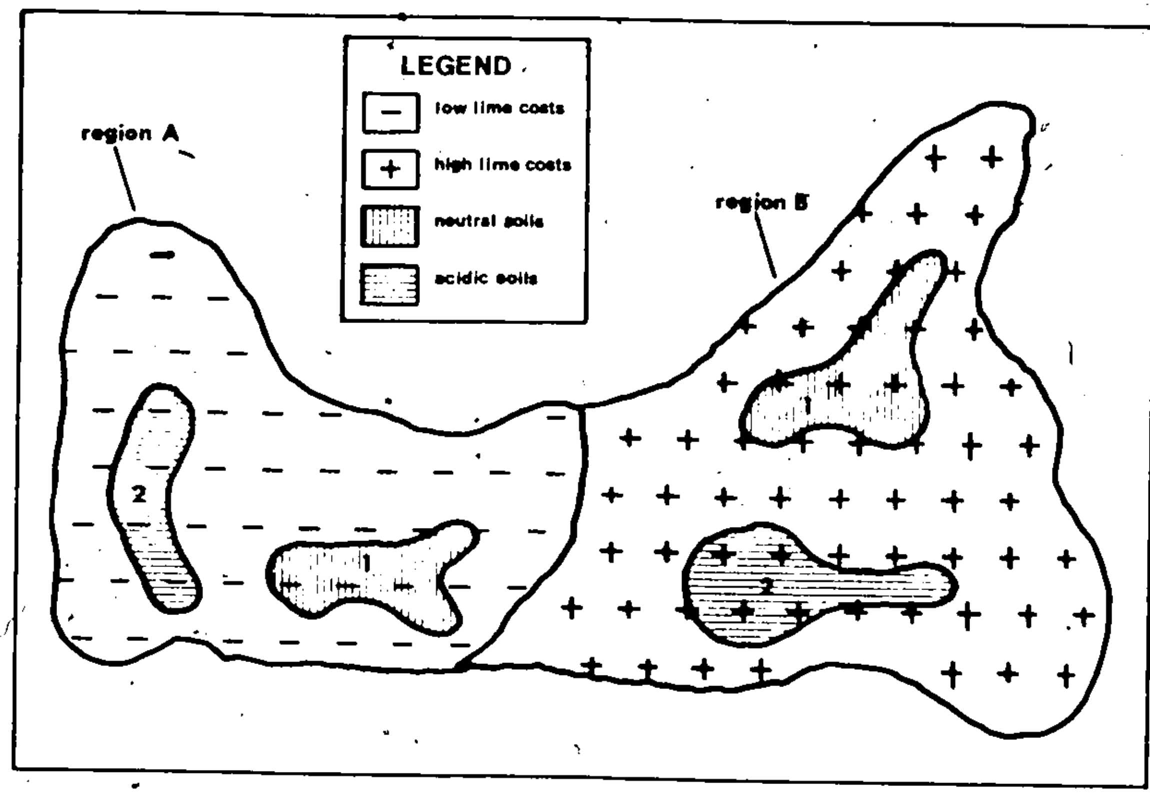
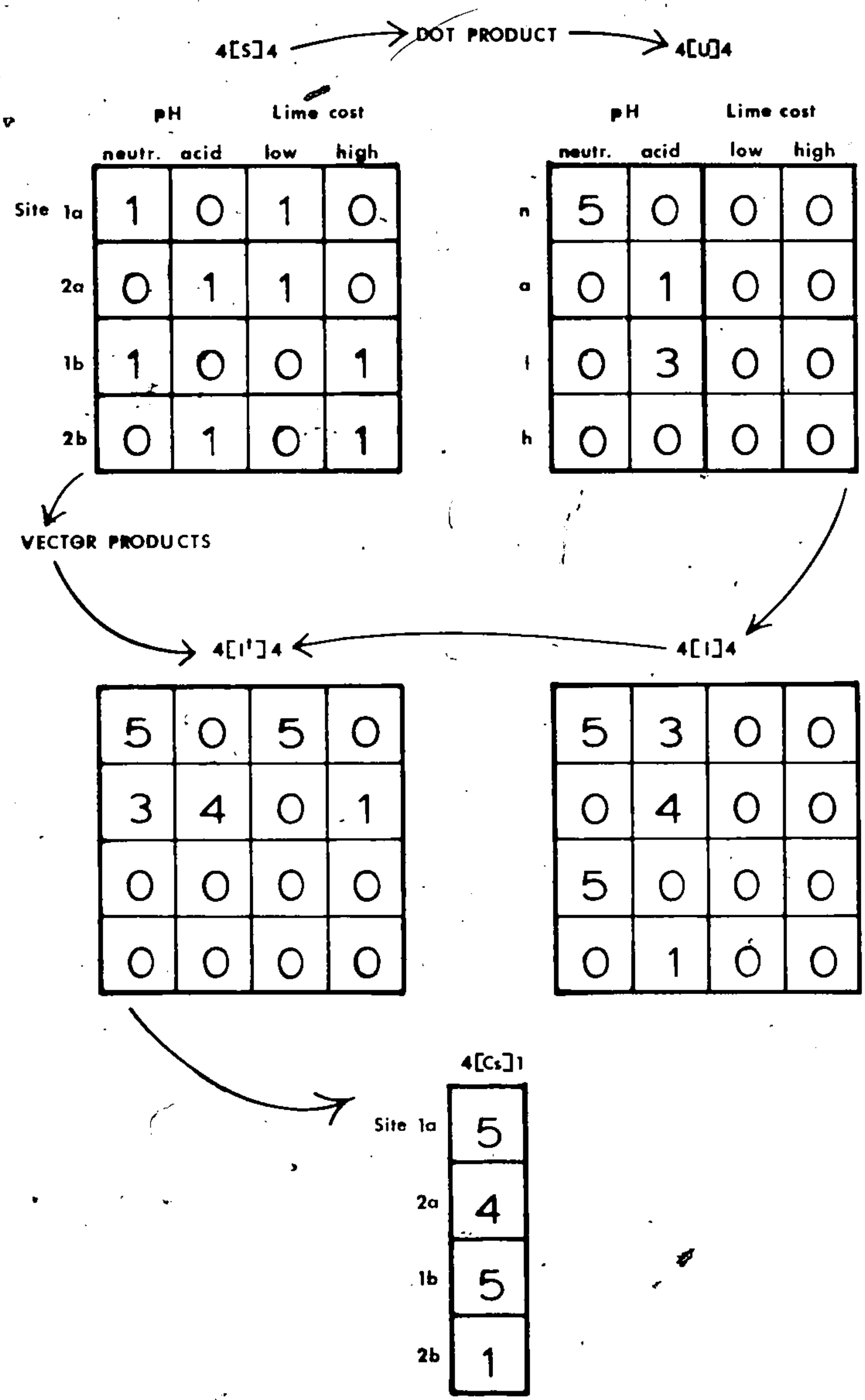


Figure 16: Hypothetical incorporation of variable "lime costs" into LASTAN



very low for obvious reasons. Had lime costs been omitted both sites 2A and 2B would have had identically low ratings.

The third envisaged improvement of LASTAN is to expand its capabilities to also include ratings of potential suitability. Described by F.A.O., (1976, p.22), potential suitability "refers to the suitability, for a defined use, of land [or soil] units in their condition at some future date, after specific major improvements have been completed where necessary". Major land improvements refer to irrigation projects, large drainage installations, land levelling, erosion control, and other ameliorations beyond the means of the farm operator. Potential suitability is a particularly important concept in areas where agricultural development projects are being considered.

LASTAN could be adapted to accommodate potential suitability by creating a three-dimensional n[S]m site array. This entity would be composed of essentially two layers of n[S]m matrices. Each row of the first layer would represent site conditions as they presently exist on each land or soil unit. The rows of the second layer would represent the predicted site conditions of each unit existing after implementing major improvement practices. Not all sites would be affected or changed from one layer to another because improvement practices would not always apply to all sites.

Two sets of suitability indices would then be generated which could be compared, in the planning stages, to the cost of making these improvements versus the gains expected from them.

## 5.4 ENCAPSULATION

The purpose of this concluding chapter has been to review what was done in this thesis, to comment upon problems that were encountered, and to suggest three avenues of future research that could apply to the LASTAN model.

It should be restressed that although emphasis has been placed upon its use in agriculture, LASTAN has potential for non-agricultural uses as well. These include those uses which have specific soil and land resource requirements. For example, studies on the feasibility of septic tank installations, reforestation sites, or suitability for specific types of building foundations would all adapt themselves well to the use of LASTAN providing that the necessary data were available.

Finally, it should also be stressed that LASTAN is only a tool, designed to aid in the determination of land suitability for different uses. It is not an end in itself. Nor does it determine best land-use for an area, even land evaluation cannot do this. All that LASTAN can do is suggest comparative physical, and with modifications, economic feasibility. The determination of best land-use involves a prior knowledge of societal objectives. Allocating "best" land-use then becomes a matter of putting land to those uses which will most efficiently achieve those objectives. It is the objective which determines what is best. If the objective is to inhabit a planet in which man lives in harmony with both his fellow man and the physical environment which surrounds him, then best land-use(s) are those which will most help in achieving this goal. Objectives are determined by value systems and levels of conciousness. They should also be put under scrutiny when attempting to plan for rational land-use.

## Appendix A

## CROP MATRIX DATA SOURCES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## Appendix B

## SELECTED BIBLIOGRAPHY ON SOIL PROPERTY INTERACTIONS


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Appendix C

*PHI-CORRELATION MATRIX*

| | I01<br>I19 | I02<br>I20 | I03<br>I21 | I04<br>I22 | I05<br>I23 | I06<br>I24 | I07<br>I25 | I08<br>I26 | I09<br>I27 | I10<br>I28 | I11<br>I29 | I<br>I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I01 ASP | 1.000 | 0.282 | 0.207 | 0.199 | 0.207 | 0.766 | 0.207 | 0.138 | 0.368 | 0.404 | 0.125 | 0. |
| | 0.362 | 0.301 | 0.404 | 0.441 | 0.367 | 0.207 | 0.403 | 0.324 | 0.090 | 0.404 | 0.106 | 0. |
| I02 BEE | 0.282 | 1.000 | 0.559 | 0.589 | 0.671 | 0.538 | 0.671 | 0.366 | 0.475 | 0.295 | 0.265 | 0. |
| | 0.151 | 0.290 | 0.074 | 0.224 | 0.282 | 0.224 | 0.308 | 0.224 | 0.224 | 0.184 | 0.327 | 0. |
| I03 BRO | 0.207 | 0.559 | 1.000 | 0.843 | 0.783 | 0.224 | 0.783 | 0.580 | 0.368 | 0.626 | 0.507 | 0. |
| | 0.397 | 0.495 | 0.305 | 0.350 | 0.441 | 0.350 | 0.447 | 0.458 | 0.350 | 0.305 | 0.537 | 0. |
| I04 BRS | 0.199 | 0.589 | 0.843 | 1.000 | 0.615 | 0.236 | 0.729 | 0.534 | 0.198 | 0.460 | 0.312 | 0. |
| | 0.312 | 0.351 | 0.235 | 0.158 | 0.446 | 0.272 | 0.471 | 0.387 | 0.272 | 0.235 | 0.386 | 0. |
| I05 CAB | 0.207 | 0.671 | 0.783 | 0.615 | 1.000 | 0.335 | 0.783 | 0.474 | 0.474 | 0.626 | 0.507 | 0. |
| | 0.287 | 0.389 | 0.305 | 0.458 | 0.441 | 0.242 | 0.335 | 0.350 | 0.350 | 0.198 | 0.431 | 0. |
| I06 CAR | 0.766 | 0.538 | 0.224 | 0.236 | 0.335 | 1.000 | 0.335 | 0.256 | 0.585 | 0.405 | 0.151 | 0. |
| | 0.378 | 0.399 | 0.295 | 0.447 | 0.282 | 0.112 | 0.423 | 0.335 | 0.224 | 0.295 | 0.218 | 0. |
| I07 CAU | 0.207 | 0.671 | 0.783 | 0.729 | 0.783 | 0.335 | 1.000 | 0.687 | 0.474 | 0.626 | 0.397 | 0. |
| | 0.397 | 0.389 | 0.305 | 0.350 | 0.441 | 0.350 | 0.447 | 0.567 | 0.242 | 0.412 | 0.431 | 0. |
| I08 CEL | 0.138 | 0.366 | 0.580 | 0.534 | 0.474 | 0.256 | 0.687 | 1.000 | 0.479 | 0.528 | 0.312 | 0. |
| | 0.205 | 0.281 | 0.318 | 0.262 | 0.483 | 0.262 | 0.585 | 0.580 | 0.155 | 0.318 | 0.431 | 0. |
| I09 COR | 0.368 | 0.475 | 0.368 | 0.198 | 0.474 | 0.585 | 0.474 | 0.479 | 1.000 | 0.633 | 0.312 | 0. |
| | 0.312 | 0.385 | 0.318 | 0.474 | 0.368 | 0.155 | 0.475 | 0.262 | 0.262 | 0.213 | 0.431 | 0. |
| I10 CUC | 0.404 | 0.295 | 0.626 | 0.460 | 0.626 | 0.405 | 0.626 | 0.528 | 0.633 | 1.000 | 0.571 | 0. |
| | 0.463 | 0.543 | 0.470 | 0.626 | 0.404 | 0.305 | 0.516 | 0.519 | 0.412 | 0.364 | 0.587 | 0. |
| I11 PEA | [illegible] | 0.265 | 0.507 | 0.312 | 0.507 | 0.151 | 0.397 | 0.312 | 0.312 | 0.571 | 1.000 | 0. |
| | [illegible] | 0.340 | 0.354 | 0.397 | 0.481 | 0.617 | 0.378 | 0.397 | 0.727 | 0.463 | 0.701 | 0. |
| I12 PEP | [illegible] | 0.405 | 0.626 | 0.573 | 0.626 | 0.295 | 0.626 | 0.318 | 0.318 | 0.576 | 0.354 | 1. |
| | 0.571 | 0.647 | 0.470 | 0.412 | 0.288 | 0.091 | 0.295 | 0.412 | 0.412 | 0.258 | 0.483 | 0. |
| I13 LET | [illegible] | 0.605 | 0.397 | 0.428 | 0.507 | 0.605 | 0.507 | 0.420 | 0.528 | 0.680 | 0.443 | 0. |
| | [illegible] | 0.340 | 0.245 | 0.397 | 0.244 | 0.287 | 0.491 | 0.287 | 0.287 | 0.245 | 0.379 | 0. |
| I14 ONI | [illegible] | 0.491 | 0.397 | 0.428 | 0.507 | 0.718 | 0.507 | 0.420 | 0.528 | 0.680 | 0.443 | 0. |
| | [illegible] | 0.340 | 0.354 | 0.397 | 0.362 | 0.287 | 0.605 | 0.287 | 0.397 | 0.245 | 0.379 | 0. |
| I15 PAR | [illegible] | 0.423 | 0.224 | 0.236 | 0.447 | 0.769 | 0.447 | 0.366 | 0.585 | 0.627 | 0.265 | 0. |
| | [illegible] | 0.399 | 0.405 | 0.559 | 0.282 | 0.112 | 0.423 | 0.335 | 0.224 | 0.295 | 0.327 | 0. |
| I16 POT | [illegible] | 0.605 | 0.397 | 0.312 | 0.617 | 0.378 | 0.617 | 0.312 | 0.312 | 0.354 | 0.220 | 0. |
| | [illegible] | 0.340 | 0.354 | 0.397 | 0.125 | 0.287 | 0.151 | 0.287 | 0.068 | 0.354 | 0.272 | 0 |
| I17 RAD | [illegible] | 0.366 | 0.368 | 0.310 | 0.474 | 0.366 | 0.368 | 0.270 | 0.374 | 0.423 | 0.636 | 0. |
| | [illegible] | 0.385 | 0.318 | 0.368 | 0.483 | 0.368 | 0.475 | 0.262 | 0.899 | 0.423 | 0.742 | 0. |
| I18 ENS | [illegible] | 0.295 | 0.519 | 0.348 | 0.519 | 0.184 | 0.519 | 0.423 | 0.423 | 0.682 | 0.897 | 0 |
| | [illegible] | 0.439 | 0.470 | 0.519 | 0.520 | 0.626 | 0.405 | 0.519 | 0.626 | 0.576 | 0.796 | 0 |



1 of 1

X*

| I06 | I07 | I08 | I09 | I10 | I11 | I12 | I13 | I14 | I15 | I16 | I17 | I18 | I24 | I25 | I26 | I27 | I28 | I29 | I30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .766 | 0.207 | 0.138 | 0.368 | 0.404 | 0.125 | 0.172 | 0.481 | 0.600 | 0.645 | 0.362 | 0.138 | 0.172 | .207 | 0.403 | 0.324 | 0.090 | 0.404 | 0.106 | 0.040 |
| .538 | 0.671 | 0.366 | 0.475 | 0.295 | 0.265 | 0.405 | 0.605 | 0.491 | 0.423 | 0.605 | 0.366 | 0.295 | .224 | 0.308 | 0.224 | 0.224 | 0.184 | 0.327 | 0.423 |
| .224 | 0.783 | 0.580 | 0.368 | 0.626 | 0.507 | 0.626 | 0.397 | 0.397 | 0.224 | 0.397 | 0.368 | 0.519 | .350 | 0.447 | 0.458 | 0.350 | 0.305 | 0.537 | 0.335 |
| .236 | 0.729 | 0.534 | 0.198 | 0.460 | 0.312 | 0.573 | 0.428 | 0.428 | 0.236 | 0.312 | 0.310 | 0.348 | .272 | 0.471 | 0.387 | 0.272 | 0.235 | 0.386 | 0.236 |
| .335 | 0.783 | 0.474 | 0.474 | 0.626 | 0.507 | 0.626 | 0.507 | 0.507 | 0.447 | 0.617 | 0.474 | 0.519 | .242 | 0.335 | 0.350 | 0.350 | 0.198 | 0.431 | 0.335 |
| .000 | 0.335 | 0.256 | 0.585 | 0.405 | 0.151 | 0.295 | 0.605 | 0.718 | 0.769 | 0.378 | 0.366 | 0.184 | .112 | 0.423 | 0.335 | 0.224 | 0.295 | 0.218 | 0.192 |
| .335 | 1.000 | 0.687 | 0.474 | 0.626 | 0.397 | 0.626 | 0.507 | 0.507 | 0.447 | 0.617 | 0.368 | 0.519 | .350 | 0.447 | 0.567 | 0.242 | 0.412 | 0.431 | 0.224 |
| .256 | 0.687 | 1.000 | 0.479 | 0.528 | 0.312 | 0.318 | 0.420 | 0.420 | 0.366 | 0.312 | 0.270 | 0.423 | .262 | 0.585 | 0.580 | 0.155 | 0.318 | 0.431 | 0.146 |
| .585 | 0.474 | 0.479 | 1.000 | 0.633 | 0.312 | 0.318 | 0.528 | 0.528 | 0.585 | 0.312 | 0.374 | 0.423 | .155 | 0.475 | 0.262 | 0.262 | 0.213 | 0.431 | 0.366 |
| .405 | 0.626 | 0.528 | 0.633 | 1.000 | 0.571 | 0.576 | 0.680 | 0.680 | 0.627 | 0.354 | 0.423 | 0.682 | .305 | 0.516 | 0.519 | 0.412 | 0.364 | 0.587 | 0.295 |
| .151 | 0.397 | 0.312 | 0.312 | 0.571 | 1.000 | 0.354 | 0.443 | 0.443 | 0.265 | 0.220 | 0.636 | 0.897 | .617 | 0.378 | 0.397 | 0.727 | 0.463 | 0.701 | 0.718 |
| .295 | 0.626 | 0.318 | 0.318 | 0.576 | 0.354 | 1.000 | 0.245 | 0.354 | 0.405 | 0.463 | 0.423 | 0.470 | .091 | 0.295 | 0.412 | 0.412 | 0.258 | 0.483 | 0.295 |
| .605 | 0.507 | 0.420 | 0.528 | 0.680 | 0.443 | 0.245 | 1.000 | 0.889 | 0.718 | 0.443 | 0.420 | 0.463 | .287 | 0.491 | 0.287 | 0.287 | 0.245 | 0.379 | 0.265 |
| .718 | 0.507 | 0.420 | 0.528 | 0.680 | 0.443 | 0.354 | 0.889 | 1.000 | 0.832 | 0.443 | 0.528 | 0.463 | .287 | 0.605 | 0.287 | 0.397 | 0.245 | 0.379 | 0.151 |
| .769 | 0.447 | 0.366 | 0.585 | 0.627 | 0.265 | 0.405 | 0.718 | 0.832 | 1.000 | 0.605 | 0.366 | 0.405 | .112 | 0.423 | 0.335 | 0.224 | 0.295 | 0.327 | 0.077 |
| .378 | 0.617 | 0.312 | 0.312 | 0.354 | 0.220 | 0.463 | 0.443 | 0.443 | 0.605 | 1.000 | 0.205 | 0.354 | .287 | 0.151 | 0.287 | 0.068 | 0.354 | 0.272 | 0.038 |
| .366 | 0.368 | 0.270 | 0.374 | 0.423 | 0.636 | 0.423 | 0.420 | 0.528 | 0.366 | 0.205 | 1.000 | 0.633 | .368 | 0.475 | 0.262 | 0.899 | 0.423 | 0.742 | 0.475 |
| .184 | 0.519 | 0.423 | 0.423 | 0.682 | 0.897 | 0.470 | 0.463 | 0.463 | 0.405 | 0.354 | 0.633 | 1.000 | 0.626 | 0.405 | 0.519 | 0.626 | 0.576 | 0.796 | 0.627 |

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| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I19 SPI | 0.362 | 0.151 | 0.397 | 0.312 | 0.287 | 0.378 | 0.397 | 0.205 | 0.312 | 0.463 | 0.331 | 0.4 |
| | 1.000 | 0.768 | 0.463 | 0.507 | 0.125 | 0.068 | 0.491 | 0.397 | 0.397 | 0.463 | 0.379 | 0.2 |
| I20 SQT | 0.301 | 0.290 | 0.495 | 0.351 | 0.389 | 0.399 | 0.389 | 0.281 | 0.385 | 0.543 | 0.340 | 0.6 |
| | 0.768 | 1.000 | 0.439 | 0.600 | 0.073 | 0.073 | 0.399 | 0.389 | 0.389 | 0.439 | 0.641 | 0.2 |
| I21 TOP | 0.404 | 0.074 | 0.305 | 0.235 | 0.305 | 0.295 | 0.305 | 0.318 | 0.318 | 0.470 | 0.354 | 0.4 |
| | 0.463 | 0.439 | 1.000 | 0.519 | 0.172 | 0.198 | 0.295 | 0.412 | 0.305 | 0.470 | 0.378 | 0. |
| I22 TUP | 0.441 | 0.224 | 0.350 | 0.158 | 0.458 | 0.447 | 0.350 | 0.262 | 0.474 | 0.626 | 0.397 | 0.4 |
| | 0.507 | 0.600 | 0.519 | 1.000 | 0.207 | 0.133 | 0.335 | 0.458 | 0.350 | 0.519 | 0.537 | 0.2 |
| I23 APL | 0.367 | 0.282 | 0.441 | 0.446 | 0.441 | 0.282 | 0.441 | 0.483 | 0.368 | 0.404 | 0.481 | 0. |
| | 0.125 | 0.073 | 0.172 | 0.207 | 1.000 | 0.441 | 0.524 | 0.441 | 0.441 | 0.404 | 0.448 | 0. |
| I24 BLB | 0.207 | 0.224 | 0.350 | 0.272 | 0.242 | 0.112 | 0.350 | 0.262 | 0.155 | 0.305 | 0.617 | 0. |
| | 0.068 | 0.073 | 0.198 | 0.133 | 0.441 | 1.000 | 0.335 | 0.350 | 0.350 | 0.519 | 0.431 | 0. |
| I25 RAS | 0.403 | 0.308 | 0.447 | 0.471 | 0.335 | 0.423 | 0.447 | 0.585 | 0.475 | 0.516 | 0.378 | 0. |
| | 0.491 | 0.399 | 0.295 | 0.335 | 0.524 | 0.335 | 1.000 | 0.447 | 0.447 | 0.405 | 0.436 | 0. |
| I26 STB | 0.324 | 0.224 | 0.458 | 0.387 | 0.350 | 0.335 | 0.567 | 0.580 | 0.262 | 0.519 | 0.397 | 0. |
| | 0.397 | 0.389 | 0.412 | 0.458 | 0.441 | 0.350 | 0.447 | 1.000 | 0.242 | 0.734 | 0.431 | 0. |
| I27 BAR | 0.090 | 0.224 | 0.350 | 0.272 | 0.350 | 0.224 | 0.242 | 0.155 | 0.262 | 0.412 | 0.727 | 0. |
| | 0.397 | 0.389 | 0.305 | 0.350 | 0.441 | 0.350 | 0.447 | 0.242 | 1.000 | 0.412 | 0.748 | 0. |
| I28 OAT | 0.404 | 0.184 | 0.305 | 0.235 | 0.198 | 0.295 | 0.412 | 0.318 | 0.213 | 0.364 | 0.463 | 0. |
| | 0.463 | 0.439 | 0.470 | 0.519 | 0.404 | 0.519 | 0.405 | 0.734 | 0.412 | 1.000 | 0.587 | 0. |
| I29 RYE | 0.106 | 0.327 | 0.537 | 0.386 | 0.431 | 0.218 | 0.431 | 0.431 | 0.431 | 0.587 | 0.701 | 0. |
| | 0.379 | 0.641 | 0.378 | 0.537 | 0.448 | 0.431 | 0.436 | 0.431 | 0.748 | 0.587 | 1.000 | 0. |
| I30 SOY | 0.040 | 0.423 | 0.335 | 0.236 | 0.335 | 0.192 | 0.224 | 0.146 | 0.366 | 0.295 | 0.718 | 0. |
| | 0.265 | 0.290 | 0.074 | 0.224 | 0.403 | 0.447 | 0.192 | 0.224 | 0.559 | 0.295 | 0.546 | 1. |



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| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.378 | 0.397 | 0.205 | 0.312 | 0.463 | 0.331 | 0.571 | 0.220 | 0.331 | 0.378 | 0.220 | 0.312 | 0.354 | 0.068 | 0.491 | 0.397 | 0.397 | 0.463 | 0.379 | 0.265 |
| 0.399 | 0.389 | 0.281 | 0.385 | 0.543 | 0.340 | 0.647 | 0.340 | 0.340 | 0.399 | 0.340 | 0.385 | 0.439 | 0.073 | 0.399 | 0.389 | 0.389 | 0.439 | 0.641 | 0.290 |
| 0.295 | 0.305 | 0.318 | 0.318 | 0.470 | 0.354 | 0.470 | 0.245 | 0.354 | 0.405 | 0.354 | 0.318 | 0.470 | 0.198 | 0.295 | 0.412 | 0.305 | 0.470 | 0.378 | 0.074 |
| 0.447 | 0.350 | 0.262 | 0.474 | 0.626 | 0.397 | 0.412 | 0.397 | 0.397 | 0.559 | 0.397 | 0.368 | 0.519 | 0.133 | 0.335 | 0.458 | 0.350 | 0.519 | 0.537 | 0.224 |
| 0.282 | 0.441 | 0.483 | 0.368 | 0.404 | 0.481 | 0.288 | 0.244 | 0.362 | 0.282 | 0.125 | 0.483 | 0.520 | 0.441 | 0.524 | 0.441 | 0.441 | 0.404 | 0.448 | 0.403 |
| 0.112 | 0.350 | 0.262 | 0.155 | 0.305 | 0.617 | 0.091 | 0.287 | 0.287 | 0.112 | 0.287 | 0.368 | 0.626 | 1.000 | 0.335 | 0.350 | 0.350 | 0.519 | 0.431 | 0.447 |
| 0.423 | 0.447 | 0.585 | 0.475 | 0.516 | 0.378 | 0.295 | 0.491 | 0.605 | 0.423 | 0.151 | 0.475 | 0.405 | 0.335 | 1.000 | 0.447 | 0.447 | 0.405 | 0.436 | 0.192 |
| 0.335 | 0.567 | 0.580 | 0.262 | 0.519 | 0.397 | 0.412 | 0.287 | 0.287 | 0.335 | 0.287 | 0.262 | 0.519 | 0.350 | 0.447 | 1.000 | 0.242 | 0.734 | 0.431 | 0.224 |
| 0.224 | 0.242 | 0.155 | 0.262 | 0.412 | 0.727 | 0.412 | 0.287 | 0.397 | 0.224 | 0.068 | 0.899 | 0.626 | 0.350 | 0.447 | 0.242 | 1.000 | 0.412 | 0.748 | 0.559 |
| 0.295 | 0.412 | 0.318 | 0.213 | 0.364 | 0.463 | 0.258 | 0.245 | 0.245 | 0.295 | 0.354 | 0.423 | 0.576 | 0.519 | 0.405 | 0.734 | 0.412 | 1.000 | 0.587 | 0.295 |
| 0.218 | 0.431 | 0.431 | 0.431 | 0.587 | 0.701 | 0.483 | 0.379 | 0.379 | 0.327 | 0.272 | 0.742 | 0.796 | 0.431 | 0.436 | 0.431 | 0.748 | 0.587 | 1.000 | 0.546 |
| 0.192 | 0.224 | 0.146 | 0.366 | 0.295 | 0.718 | 0.295 | 0.265 | 0.151 | 0.077 | 0.038 | 0.475 | 0.627 | 0.447 | 0.192 | 0.224 | 0.559 | 0.295 | 0.546 | 1.000 |

Appendix D

# INTERPRETATION OF FACTORS GENERATED BY PRINCIPAL COMPONENTS ANALYSIS

With the aid of the data matrix and a knowledge of the crop soil requirements, factors were interpreted as follows:

FACTOR ONE explains 42% of the variation in the matrix. The high positive loadings of every crop upon this factor (ranges from +0.819 for CUC to +0.478 for BLB) indicate that this is a dimension of variation to which all crops respond similarly. It is a general factor which implies that, up to a certain point, all crops examined in this study behave similarly in response to variation in the values of soil properties represented by it. Thus, it is perhaps a representation of the average or mean requirements of the population of crops as a whole. Because of its lack of ability to clearly define distinct clusters this factor was not used as an aid in the classification of crops into groups. It was, however, useful in interpreting some of the factors.

FACTOR TWO accounts for over 10% of the total variation in soil requirements. Unlike factor one, it shows high negative loadings in addition to high positive ones. These range between -0.536 for PEA to +0.547 for CAR.

This factor was interpreted as best defining general nutrient requirements of crops. Those crops loading low had, in general, low NNN,PPP,KKK requirements whereas those loading high had correspondingly higher requirements for these nutrients.

<u>FACTOR THREE</u> explains nearly 8% of the total variation in the behavior of crops responding to changing soil conditions. Like factor two it reveals certain polarities of high and low loading crops. However, these are spread more along a continuum or continuous gradient with significantly less clustering than factor two.

Loadings range from +0.565 for BRS to -0.390 for TUR. This factor was interpreted as representing the general moisture requirements within the populatation of crops. Those crops loading negatively to neutral had low to medium water requirements. Those crops loading positively had higher needs.

<u>FACTOR FOUR</u> handles 6.6% of the total variation within the population of crops. The highest loadings were found with SPI and SQU possessing values of +0.497 and +0.496 respectively. Those crops loading lowest were LET and ONI at -0.375 and -0.393.

This factor was, at first, difficult to interpret. However, once understood, it provided some very interesting results. Observed here is visible evidence of the importance of <u>ranges</u> of optimum soil conditions in addition to actual values of these conditions.

Textural requirements best represent the meaning of this factor. Those crops loading low not only preferred lighter textured soils but, in addition, grew best under a relatively narrow range of textural conditions. These are, in general, sandy-loams to loams. On the other hand, the high loading crops had somewhat wider textural tolerances, but tended to prefer slightly heavier textures.

FACTOR FIVE was the last factor of any discernible significance used in crop grouping. It explained almost 5.5% of the total variation within the population of crops. These crops loading highest on this factor were OAT, STB, and BLB at +0.533, +0.455, and +0.381 respectively. The lowest loadings on this factor were held by SQU, BAR, and PEP at -0.276, -0.287, and -0.281 respectively.

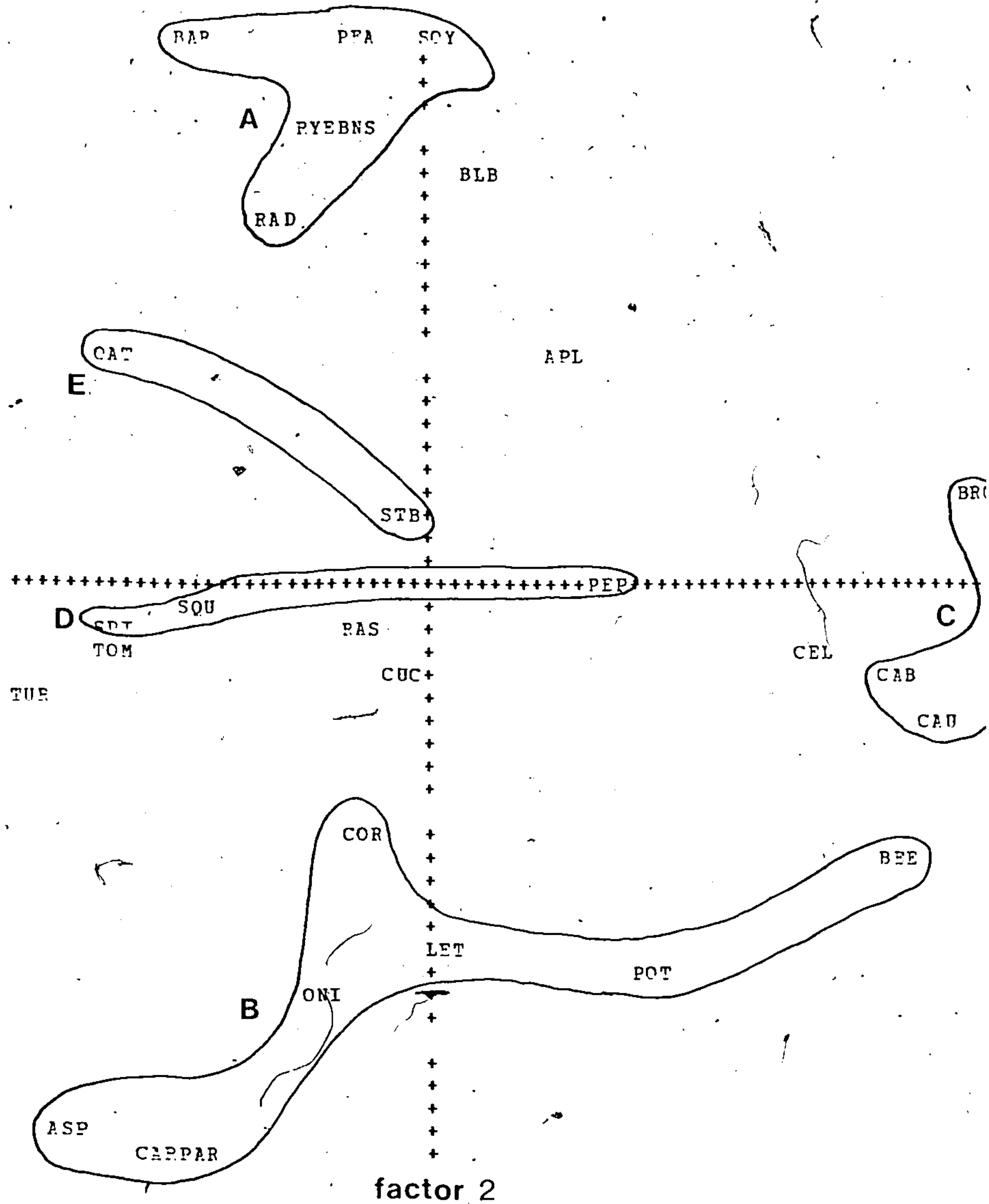
Interpreted as representing varying preferences in soil reaction for optimum growth, this factor encompasses not only values of pH requirements but also ranges of preferences as well. In this way it behaves similarly to factor four.

Those crops loading high had relatively narrow ranges of preferred soil reactions which spanned no more than two classes; that is, a range of one unit of pH. Treated individually, these crops tended to prefer very acid to slightly acid soil conditions.

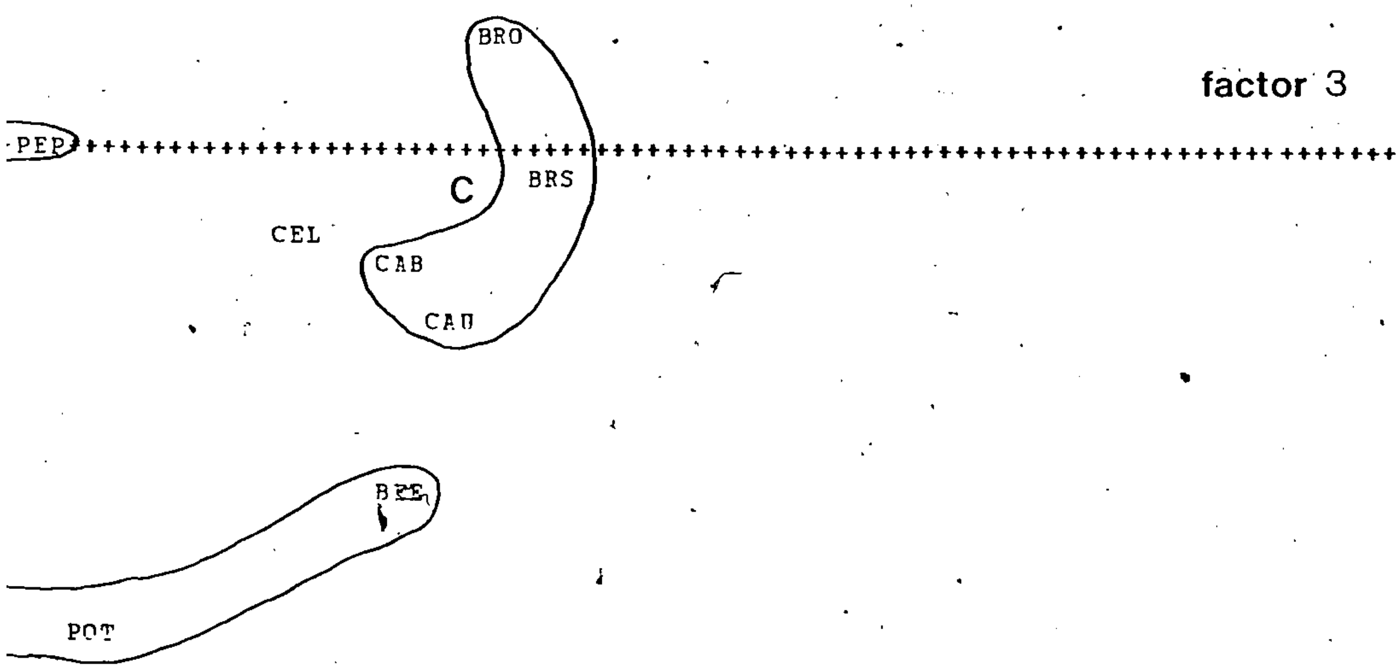
Another large group of crops also had narrow preferences with regard to pH. These crops tended to load around zero (0) on this factor. Their pH requirements were generally in the moderately acid range and centered about the 5.5 level.

A third group of crops had slightly wider ranges of tolerances which spanned, in some cases, up to three classes (ie. up to two pH units). These crops all preferred slightly acid to alkaline soil reactions for optimum growth.

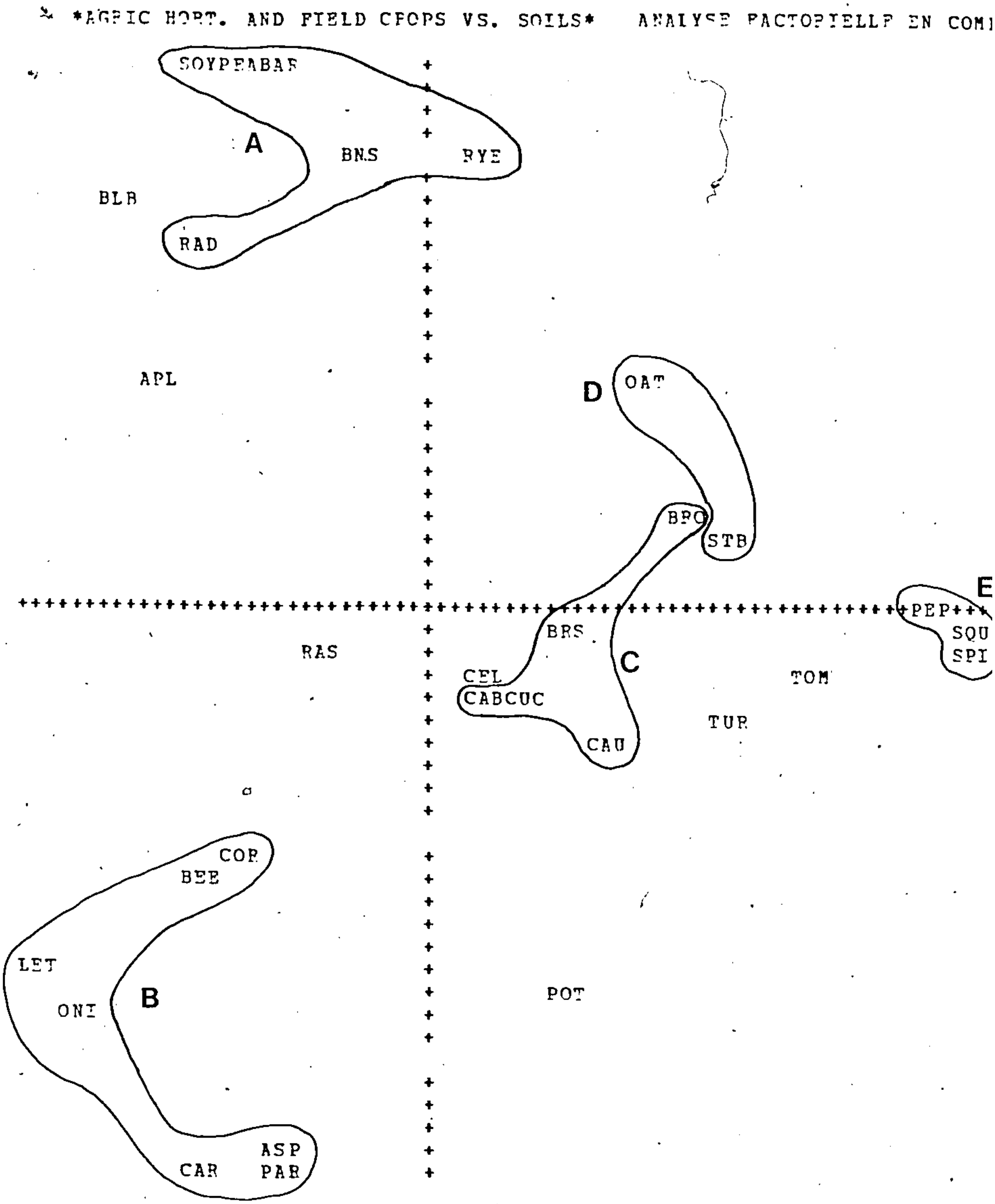
*AGRIC HORT. AND FIELD CROPS VS. SOILS*   ANALYSE FACTORIELLE EN COM



ANALYSE FACTORIELLE EN COMPOSANTES PRINCIPALES PLAN ( 2, 3)




2 of 2

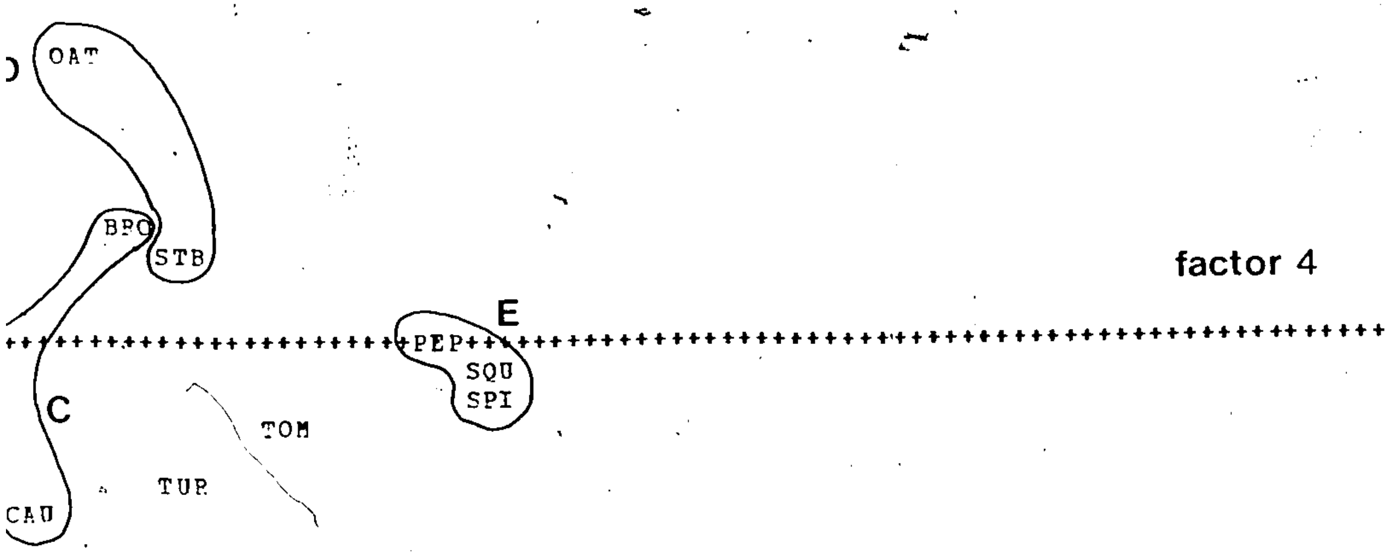



factor 2

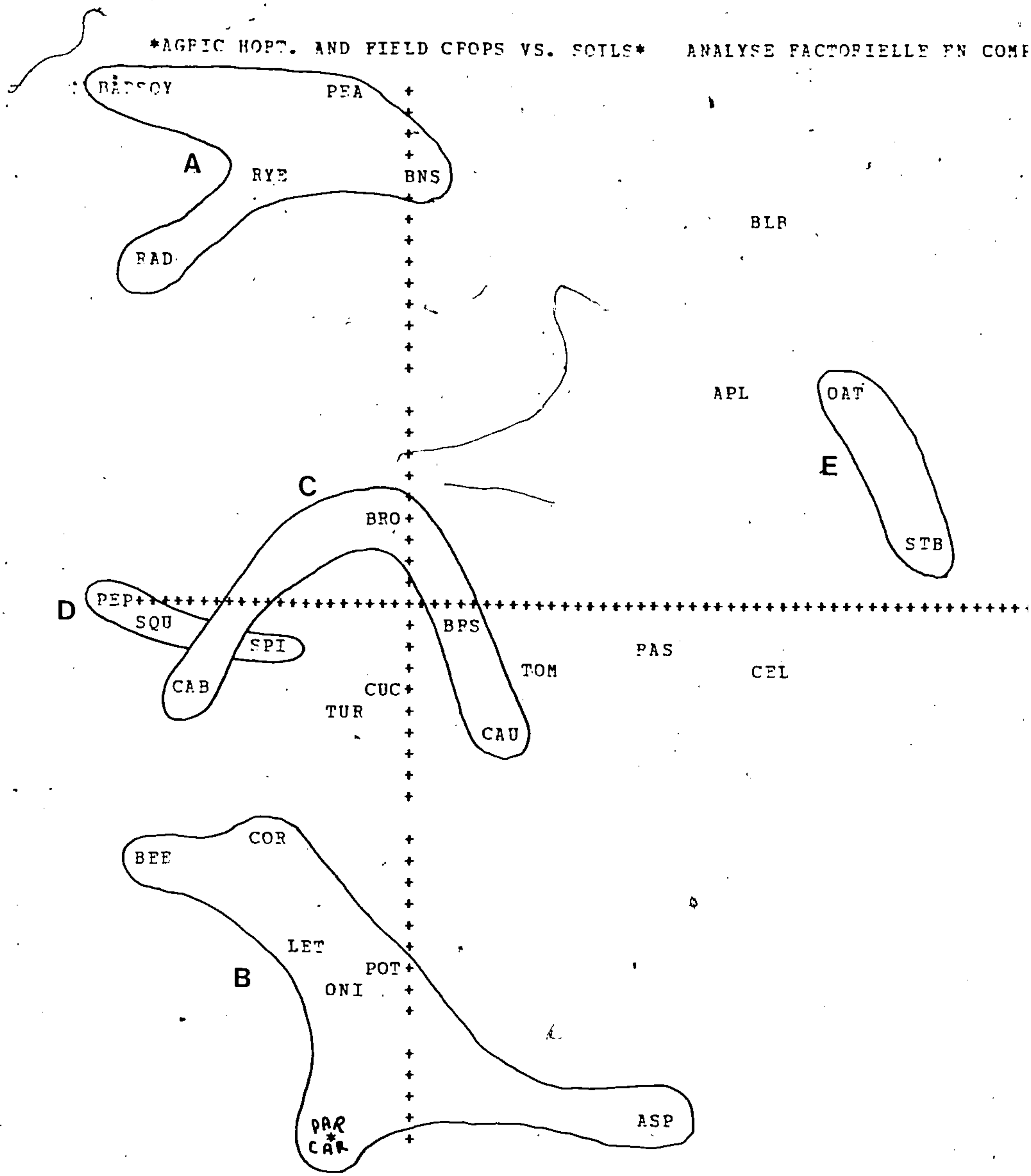


1 of 1

ANALYSE FACTORIELLE EN COMPOSANTES PRINCIPALES PLAN ( 2, 4)

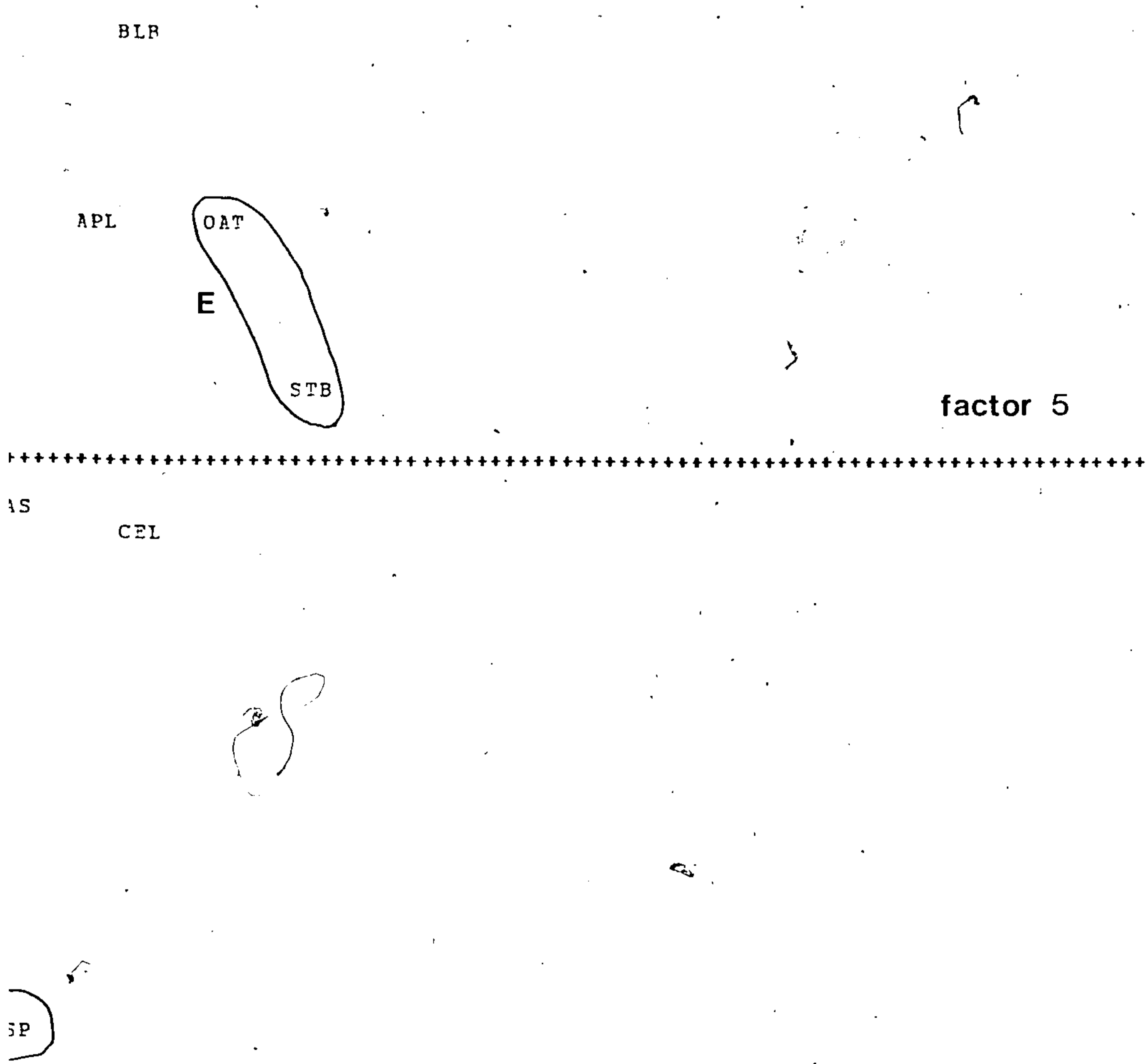



2 of 2


*AGRIC HORT. AND FIELD CROPS VS. SOILS*
ANALYSE FACTORIELLE EN COMP
PEA
A
RYE
BNS
RAD
BLB
APL
OAT
E
STB
C
BRO
PEP
D
SQU
SPI
CAB
CUC
TUR
BRS
TOM
PAS
CEL
CAU
COR
BEE
LET
B
POT
ONI
PAR
CAR
ASP

factor 2

ANALYSE FACTORIELLE EN COMPOSANTES PRINCIPALES PLAN ( 2, 5)

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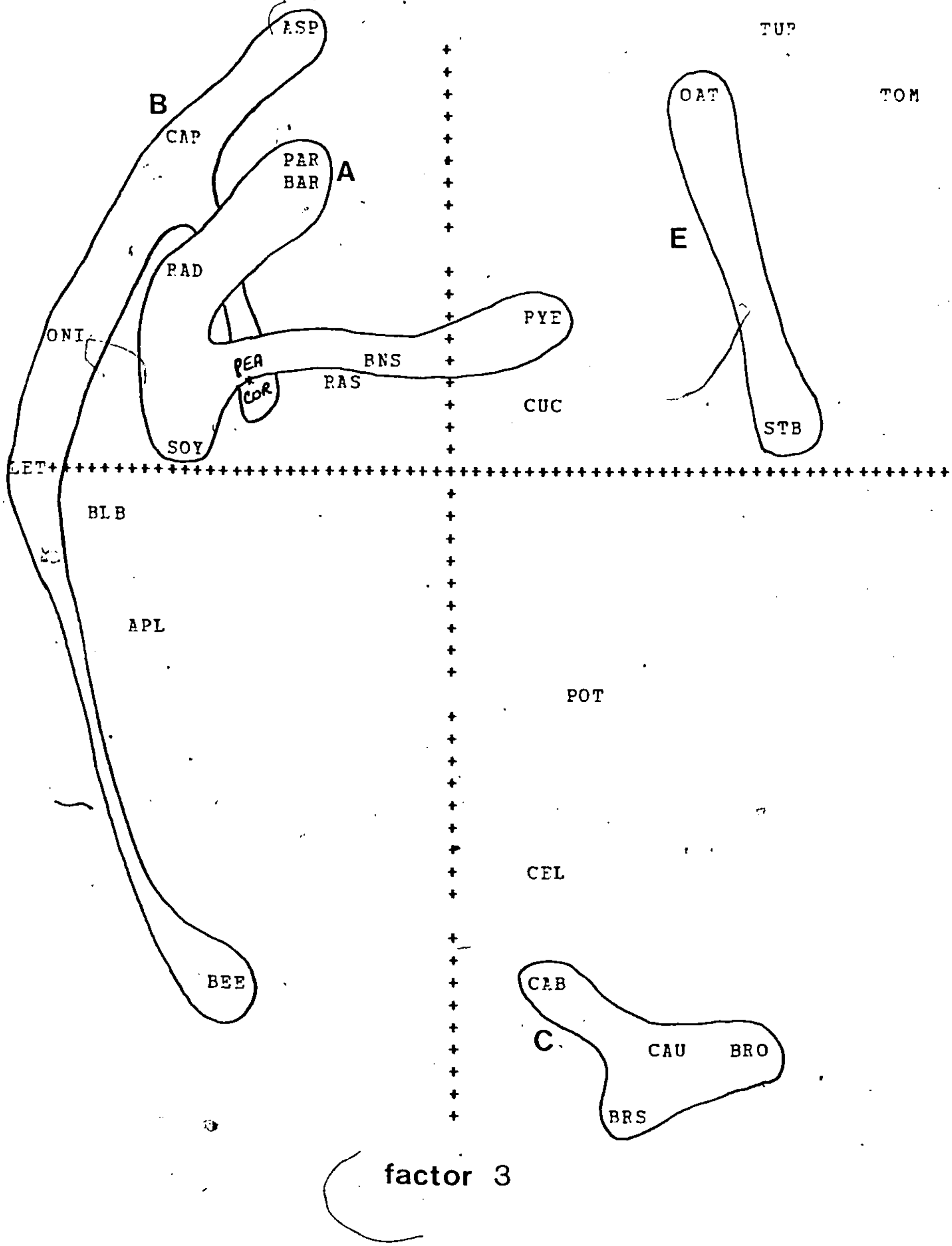
*AGRIC HORT. AND FIELD CROPS VS. SOILS* ANALYSE FACTORIELLE EN COM



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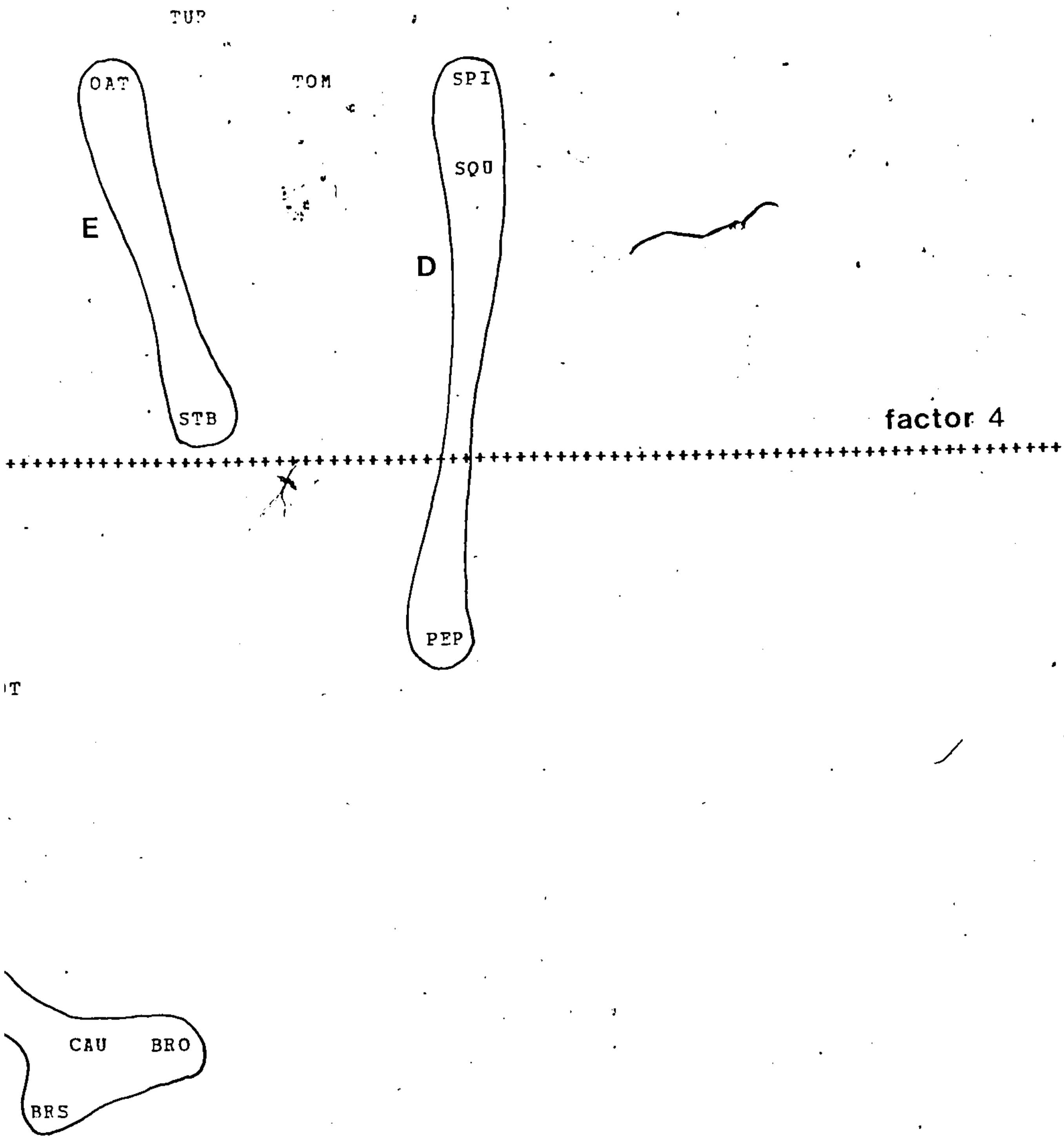
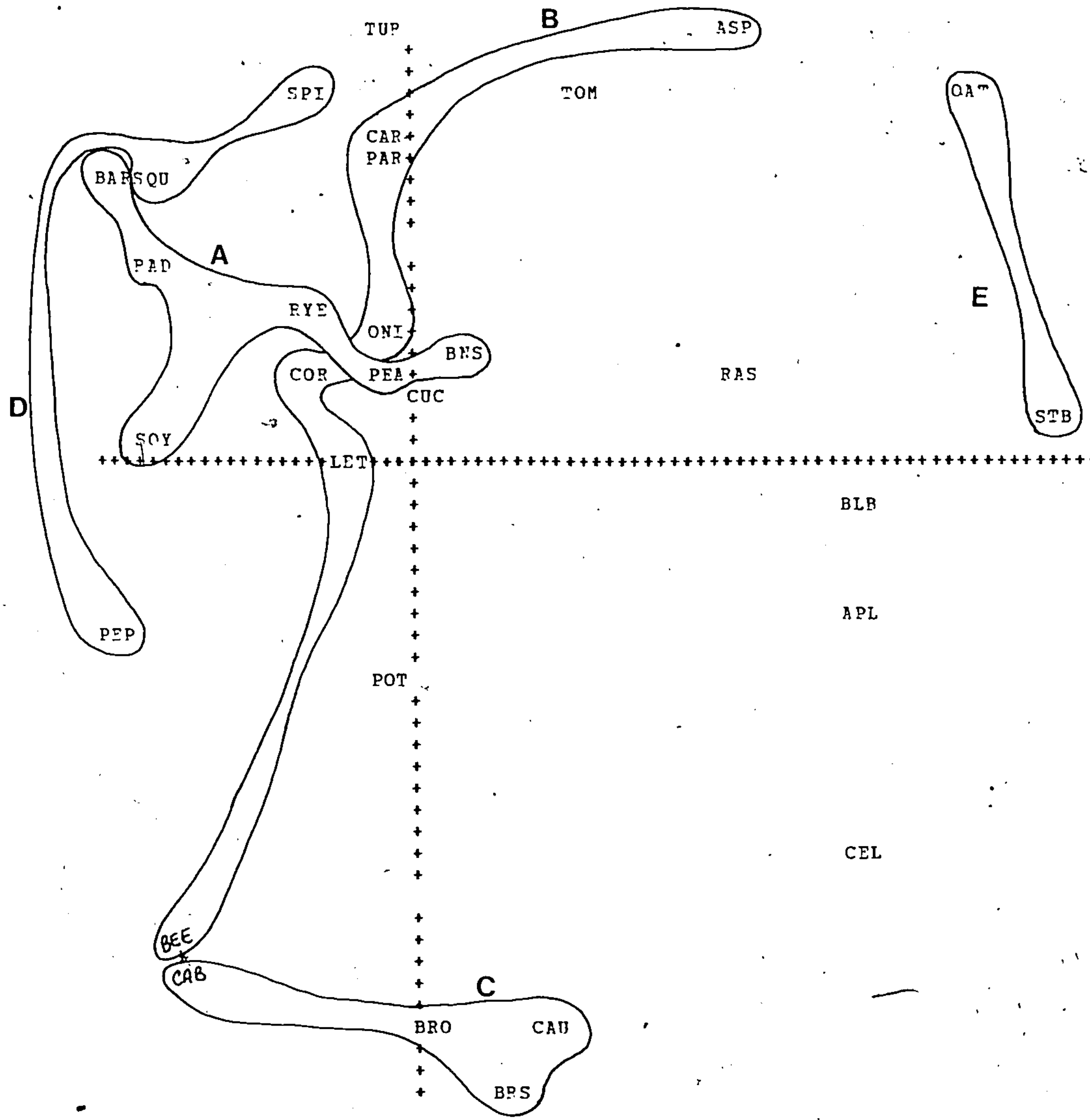
ANALYSE FACTORIELLE EN COMPOSANTES PRINCIPALES PLAN ( 3, 4)




2 of 2

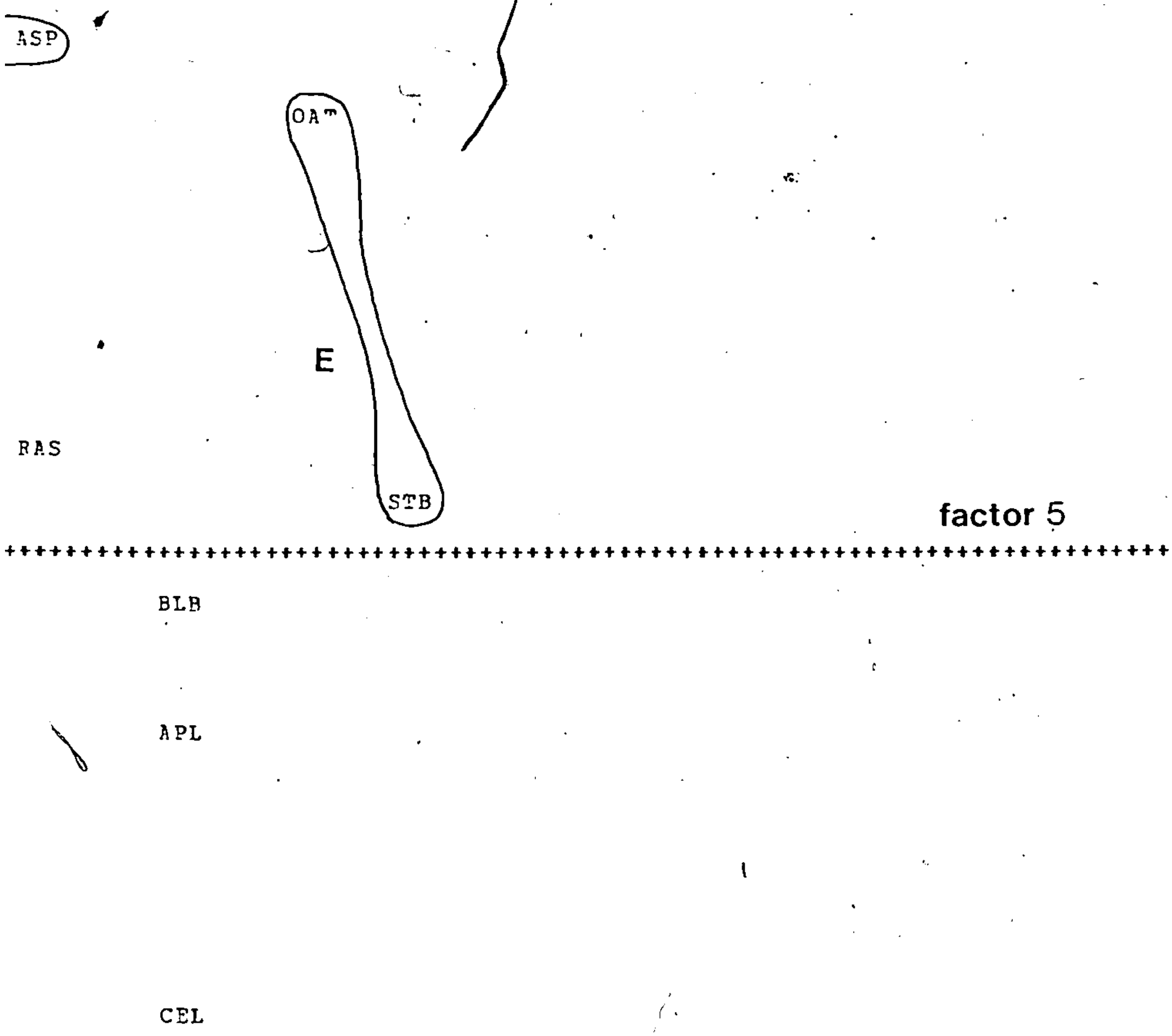



factor 3

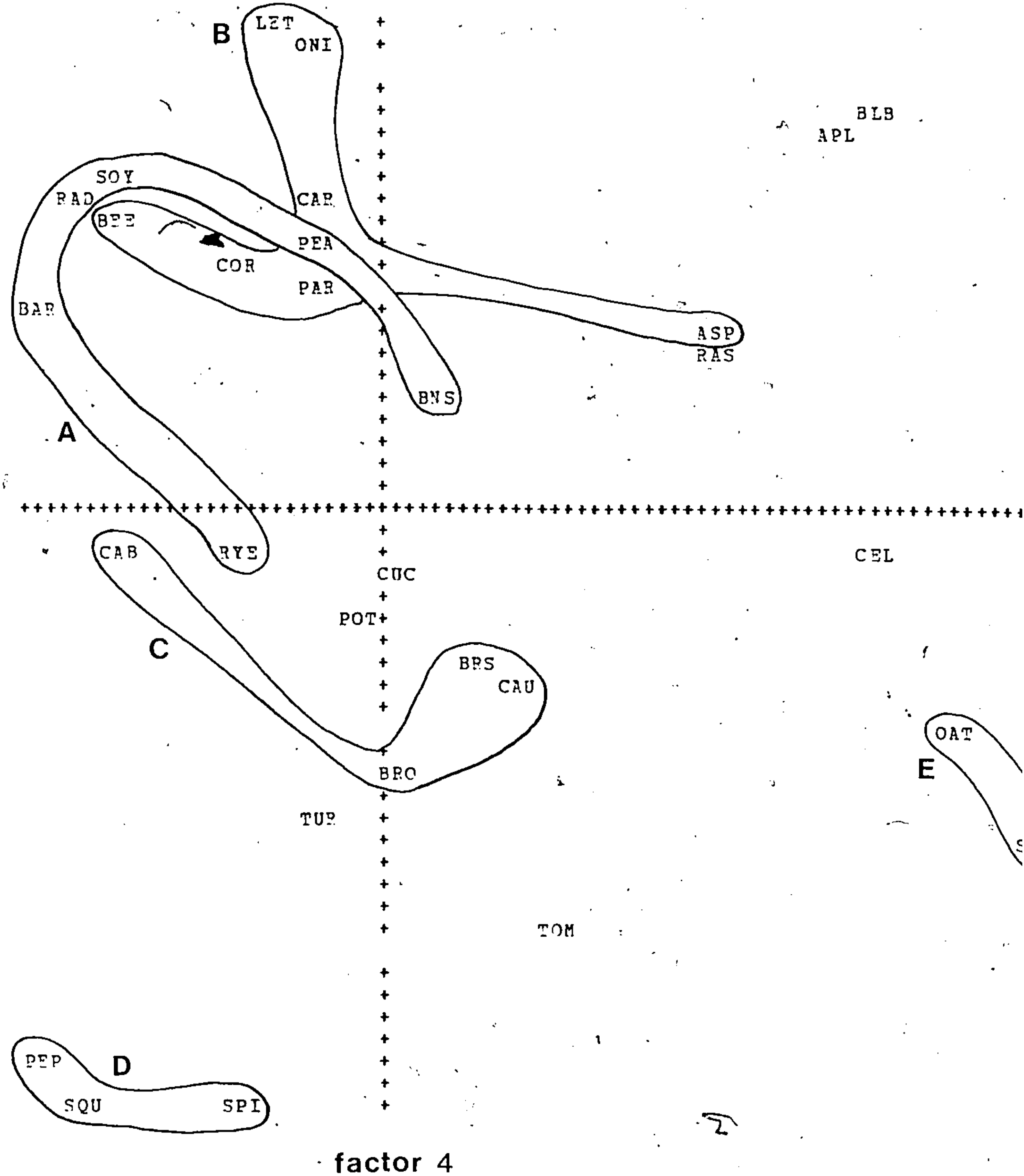


1 of 1

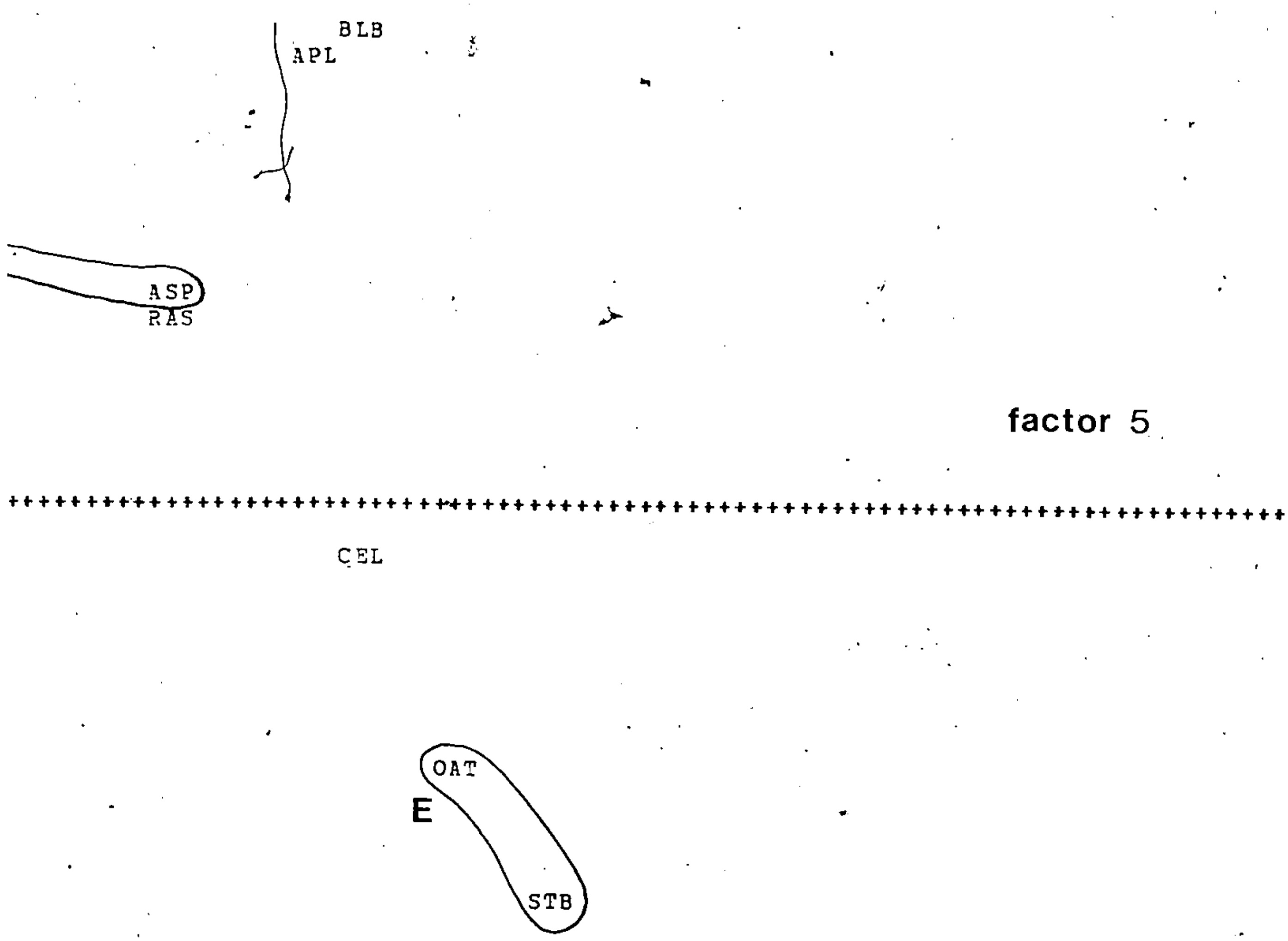
NALYSE FACTORIELLE EN COMPOSANTES PRINCIPALES PLAN ( 3, 5)



*AGRIC HORT. AND FIELD CROPS VS. SOILS*   ANALYSE FACTORIELLE EN COMPOS



ANALYSE FACTORIELLE EN COMPOSANTES PRINCIPALES PLAN ( 4, 5)

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## Appendix E

## CROP GROUPS IN MORE DETAIL

### E.1 GROUP A

To be noted is this group's low requirements for available nutrients NNN,PPP, and KKK. The legumes, of course, have the capacity to fix nitrogen (otherwise unavailable to other plants) from the air and hence need little nitrogen in the soil in order to flourish. This fact necessitates adequate drainage and aeration to the roots. BAR, RYE, and RAD, although unable to fix atmospheric nitrogen, do not have high requirements either. These crops are also low users of potassium and phosphorus.

Optimal pH levels for this group range between 6.0 and 7.2 (slightly acid to alkaline). They have a fairly wide range of textural preferences, thriving in sandy-loams to clay-loams. SOY is perhaps an extreme case with the ability to thrive in fertile clays, (DUBE, 1977, p.38). However, it is doubtful whether this characteristic applies to the Ottawa area because SOY, in this region, approaches its northern limit. The temperatures of clay soils at the beginning of the growing season are probably too low to ensure a timely maturity date for harvest. With the exception of RAD, these crops are not known to do well on organic soils.

Group A crops all grow well in soils which exceed 0.9 meters depth and BAD and RYE would even flourish in well-drained soils of lesser depth if other requirements were met. In addition, all are high to heavy water users preferring between 0.38 to 0.60 centimeters per twenty-four hours. However, no member of this group can stand excessive soil moisture.

Agriculturally, SOY, BNS, and PEA are sometimes employed in rotations where the harvested stocks are plowed under in order to revitalize structure and replenish soil nutrients. As a group then, they would be strongly related to high valued crops with similar soil requirements other than nutrients. In a dairy system a common rotation would be COR followed by one of the above. In a mixed or large market garden system two years of either SOY, BNS, or PEA would be followed by either group B or C crops, (O.M.A.F., 1978, pers. comm).

In a farming enterprize where rotations are not practised the group A crops would most likely be grown on soils less well endowed with nutrients. See Table 12 for the individual crop and averaged soil requirements for group A.

TABLE 13

Description of variables and variable states used in data matrix

| VARIABLE | CLASS | DESCRIPTION | | |
|---|---|---|---|---|
| SPH | 01 | Very strongly acid | 5.0 | |
| | 02 | Strongly acid | 5.0-5.4 | |
| | 03 | Moderately acid | 5.5-5.9 | |
| | 04 | Slightly acid | 6.0-6.7 | |
| | 05 | Neutral | 6.8-7.2 | |
| | 06 | Slightly alkaline | 7.2 | |
| TEX | 01 | Fine sand | | |
| | 02 | Sandy loam | | |
| | 03 | Loam | | |
| | 04 | Clay loam | | |
| | 05 | Clay | | |
| | 06 | Muck | | |
| NNN | 01 | Very low | 0-26 | (kg/ha available) |
| | 02 | Low | 27-53 | |
| | 03 | Medium | 54-80 | |
| | 04 | High | 81-107 | |
| | 05 | Very high | 108-134 | |
| PPP | 01 | Very low | 15-47 | (kg/ha available) |
| | 02 | Low | 48-80 | |
| | 03 | Medium | 81-113 | |
| | 04 | High | 114-146 | |
| | 05 | Very high | 147-179 | |
| KKK | 01 | Very low | 20-69 | (kg/ha available) |
| | 02 | Low | 70-119 | |
| | 03 | Medium | 120-169 | |
| | 04 | High | 170-219 | |
| | 05 | Very high | 220--270 | |
| ORD | 01 | Very shallow | 0.3-0.8 | (metres) |
| | 02 | Shallow | 0.9-1.4 | |
| | 03 | Intermediate | 1.5-2.0 | |
| | 04 | Deep | 2.1-2.6 | |
| | 05 | Very deep | 2.7 | |
| WCN | 01 | Moderate | 0.2-0.3 | (cm/24hr) |
| | 02 | High | 0.38-0.48 | |
| | 03 | Heavy | 0.50-0.60 | |
| | 04 | Very heavy | 0.60 | |
| ODR | 01 | Medium | | |
| | 02 | High | | |
| | 03 | Very high | | |

TABLE 12

Group A soil requirements

Individual crop requirements

| | SPH 123456 | TEX 123456 | NNN 12345 | PPP 12345 | KKK 12345 | ORD 12345 | WCN 1234 | ODR 123 |
|---|---|---|---|---|---|---|---|---|
| PEA | 000100 | 001100 | 10000 | 10000 | 10000 | 01111 | 0110 | 011 |
| RAD | 000111 | 011101 | 01000 | 10000 | 10000 | 01111 | 0110 | 001 |
| BNS | 001100 | 011100 | 10000 | 10000 | 10000 | 01111 | 0110 | 011 |
| BAR | 000111 | 001100 | 01000 | 10000 | 10000 | 01111 | 0110 | 001 |
| RYE | 001110 | 011100 | 01000 | 10000 | 10000 | 11111 | 0110 | 011 |
| SOY | 000110 | 001110 | 10000 | 10000 | 10000 | 00111 | 0010 | 011 |

Group A requirements

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A | 000110 | 011100 | 11000 | 10000 | 10000 | 01111 | 0110 | 011 |

## E.2 GROUP B

Group B crops grow ~~best~~ in slightly acid (pH=6.0-6.7) sandy-loams, loams, or muck soils which are very high in available nitrogen, possess medium amounts of available phosphorus and are low in available potassium. In general they are very sensitive to poor drainage but nonetheless require adequate soil moisture. Also, because this group is composed primarily of root crops, and perennials it prefers fairly deep soils.

A comparison of group A soil requirements with those of B shows that the latter are relatively more demanding than the former. In other words, the range of conditions under which the former flourish is narrower than those of the latter. This infers that, except on muck soils, group A crops can grow well any-where that group B thrives. The reverse situation, however, is not necessarily the case.

TABLE 14

Group B soil requirements

Individual crop requirements

| | SPH 123456 | TEX 123456 | NNN 12345 | PPP 12345 | KKK 12345 | ORD 12345 | WCN 1234 | ODR 123 |
|---|---|---|---|---|---|---|---|---|
| BEE | 000110 | 010001 | 00001 | 00010 | 00100 | 01111 | 0010 | 011 |
| COR | 001110 | 011101 | 00010 | 00100 | 01000 | 00111 | 0011 | 011 |
| ASP | 000100 | 111001 | 00001 | 00100 | 01000 | 00011 | 1000 | 001 |
| CAR | 000110 | 011001 | 00001 | 00100 | 01000 | 00111 | 1000 | 001 |
| PAR | 001100 | 011001 | 00001 | 00100 | 01000 | 00111 | 0100 | 001 |
| ONI | 000100 | 011001 | 00001 | 00100 | 01000 | 01111 | 0110 | 001 |
| LET | 000100 | 010001 | 00001 | 00100 | 01000 | 01111 | 0110 | 011 |

Group B requirements

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| B | 000100 | 011001 | 00001 | 00100 | 01000 | 00111 | 0110 | 001 |

## E.3 GROUP C

The soil requirements of the cole crops are characterized by relatively narrow optimum pH ranges (slightly acidic: pH= 6.0-6.7) similar to those preferred by group B, and textural preferences which range from sandy-loam to clay-loam. CAB, and CAU also both do well on muck soils, provided that drainage is excellent but moisture plentiful.

Although their demands for available nitrogen are lower than those of group B, the cole crops need more PPP and KKK than either group A or B. These high nutrient requirements are, in fact, one of the principal characteristics of cole crops. Consequently, growing them on the same soil over several consecutive years is explicitly not recommended by horticulturalists, (THOMSON & KELLY, 1957, p.277).

In both linkage and information analysis as well as P.C.A. this group is associated with other crops and crop groups. Individual crops with which it appears to associate are BEE and CEL. BEE was not included in this group for reasons given above. CEL was disregarded because its soil requirements with regard to pH, PPP, and ORD did not agree with those of the rest of the group.

Group C crops are also often seen associated with TOM and TUR (see P.C.A. graphs of factor two versus factors four and five, and four versus five). However, the differences in water requirements (see P.C.A. graph of factor 3 versus 5) plus TOM's sensitivity to frost, and thus its unsuitability for muck soils in this area, caused them not to be grouped together.

TABLE 15

Group C soil requirements

Individual crop requirements

| | SPH 123456 | TEX 123456 | NNN 12345 | PPP 12345 | KKK 12345 | ORD 12345 | WCN 1234 | ODR 123 |
|---|---|---|---|---|---|---|---|---|
| BRO | 000100 | 011100 | 00100 | 00010 | 00100 | 11111 | 0010 | 011 |
| BRS | 000100 | 010000 | 00100 | 00010 | 00100 | 11111 | 0010 | 001 |
| CAB | 000100 | 011101 | 00100 | 00010 | 00100 | 00111 | 0110 | 011 |
| CAU | 001100 | 011001 | 00100 | 00010 | 00100 | 01111 | 0010 | 011 |

Group C requirements

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G | 000100 | 011000 | 00100 | 00010 | 00100 | 01111 | 0010 | 011 |

## E.4 GROUP D

The chief characteristics of group D, which separate it from groups A, B, and C are the wide textural and reaction ranges under which it will flourish. Also to be noted are its low rates of water consumption. The P.C.A. factor graphs (especially 4 versus 5, and both of these versus 3), aptly demonstrate these characteristics. See Table 16 for this group's soil requirements.

TABLE 16

Group D soil requirements

Individual crop requirements

| | SPH 123456 | TEX 123456 | NNN 12345 | PPP 12345 | KKK 12345 | ORD 12345 | WCN 1234 | ODR 123 |
|---|---|---|---|---|---|---|---|---|
| SPI | 001100 | 001110 | 01000 | 00010 | 01000 | 01111 | 1000 | 001 |
| SQU | 001110 | 011110 | 01000 | 00010 | 01000 | 11111 | 1100 | 011 |
| PEP | 001110 | 011110 | 00100 | 00010 | 00100 | 01111 | 0100 | 001 |

Group D requirements

| | SPH 123456 | TEX 123456 | NNN 12345 | PPP 12345 | KKK 12345 | ORD 12345 | WCN 1234 | ODR 123 |
|---|---|---|---|---|---|---|---|---|
| D | 001110 | 011110 | 01000 | 00010 | 01000 | 01111 | 1100 | 001 |

E.5 GROUP E

Examination of the relevant portion of the original data matrix confirms these results, (see table ). The chief characteristics of this group are its low demands for water as well as its tolerance for more imperfect drainage conditions than the other groups. In addition this group grows best on lighter textured soils of moderate to slight acidity and requires, in general, only moderate quantities of available nutrients. It seems that these crops are more suited to poorer quality soils than are perhaps group B or C or even group D crops.

TABLE 17

Group E soil requirements

Individual crop requirements

| | SPH 123456 | TEX 123456 | NNN 12345 | PPP 12345 | KKK 12345 | ORD 12345 | WCN 1234 | ODR 123 |
|---|---|---|---|---|---|---|---|---|
| STB | 001100 | 011000 | 00100 | 01000 | 10000 | 01111 | 1000 | 111 |
| OAT | 001100 | 111000 | 01000 | 10000 | 10000 | 01111 | 1000 | 111 |

Group E requirements

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| E | 001100 | 011000 | 01100 | 11000 | 10000 | 01111 | 1000 | 111 |

## Appendix F

### LASTAN PROGRAM WITH EXPLANATION OF "LIMITING FACTOR" ALGORITHM

```
C             CHRIS LOK, DEPT. OF GEOGRAPHY, UNIV. OF OTTAWA
C               ***LASTAN: LAND SUITABILITY ANALYSIS***
C
C     THIS PROGRAM READS DATA ON LAND CONDITIONS AND USE
C     REQUIREMENTS.  IT THEN CALLS A SUBROUTINE 'SINDEX'
C     WHICH CALCULATES:  A) A SUITABILITY INDEX
C                        B) POSSIBLE PROBLEM LAND FACTORS
C                           FOR EACH USE ON EACH SITE.
C
C     SITES ARE DESCRIBED BY A SERIES OF BINARY VECTORS
C     REPRESENTING VARIABLE STATES: 0=CONDITION PRESENT
C                                   1=CONDN. NOT PRESENT
C
C     EACH USE IS DESCRIBED BY A MATRIX. ROWS AND COLS OF MATRIX
C     CORRESPOND TO THE VARIABLE STATES USED TO DESCRIBE SITES.
C     THE DIAGONAL ENTRIES OF EACH MATRIX ARE RATED ON A SCALE OF
C     1 TO 5: (5=EXCELLENT, 4=GOOD, 3=MEDIOCRE, 2=POOR, 1=UNSUITED).
C     ENTRIES OF SUBMATRICES BELOW THE DIAGONALS ARE THE 2-WAY
C     INTERACTIONS WHICH EXSIST BETWEEN VARIABLE STATES.
C
C     INPUT PARAMETERS READ:
C         N= NO. ROWS OF SITE MATRIX, NO. SITES TO BE ASSESSED (MAX=150
C         M= NO. COLS OF SITE MATRIX, ROWS & COLS OF USE MATRIX,
C            TOTAL VARIABLE STATES (MAX=50)
C         P= NO. OF DIFFERENT USES (MAX=5)
C         NVARS= TOTAL NO. VARIABLES (LAND FACTORS), MAX =10.
C         TITLE= CHARACTER VECTOR, TITLE OF PROJECT (A60 FORMAT)
C         VSNO= INTEGER VECTOR, LENGTH NVARS, EACH ENTRY EQUALS
C               THE NO. OF VARIABLE STATES IN VARIABLE(NVAR).
C         SIFT= INPUT FORMAT W/ WHICH SITE MATRIX TO BE READ,
C                MUST BEGIN W/: (A15,1X...)
C         UIFT1= INPUT FORMAT W/ WHICH USE 3-DIMENSIONAL ARRAY
C               TO BE READ. EACH MATRIX (2-D)= 1 USE.
C         UIFT2= ALTERNATE INPUT FORMAT W/ WHICH USE 3-D ARRAY READ
C                WHEN ROW ENTRIES >35, IE NEED >1CARD PER ROW.
C         VNAMES= CHARACTER VECTOR, LENGTH NVARS, 3 CHAR. NAMES OF
C                 EACH VARIABLE
C         UNAMES= CHARACTER VECTOR, LENGTH P, NAME OF EACH
C                 USE, ('P'A80) FORMAT IE. 1 CARD PER USE
C         UNFT= INPUT FORMAT W/ WHICH "UNAMES" TO BE READ
C         VST= CHARACTER VECTOR, LENGTH M, CLASS NO. OF EACH
C              VARIABLE STATE
C         VDS= CHARACTER VECTOR, LENGTH M, DESCR. OF EACH
```

```
C               VARIABLE STATE, (A60 FORMAT)
C         SNAMES= CHARACTER VECTOR, LENGTH N, DESCR. ID OF
C                 EACH SITE ('N'A15)
C
C      INPUT DATA READ:
C         SITE= N*M, 2-D REAL ARRAY OF BINARY VECTORS DESCRIBING
C               LAND CONDITIONS OF SITES.
C         CGIM= M*M, 2-D REAL ARRAY, 1 PER USE, DESCRIBES PERFORMANCE OF
C               USE UNDER EACH POSSIBLE CONDITION, TAKING INTO ACCOUNT
C               INTERACTIONS BETWEEN CONDITIONS.
C
C
C
C DECLARATION AND DIMENSIONING OF VARIABLES
C
      REAL SITE(150,50)/7500*0.0/,CGIM(50,50)/2500*0.0/,SIDX(150)
     *     /150*0.0/
      INTEGER SROW,SCOL,UROW,UCOL,UPLN,N,M,P,NVARS,R,C,T,VSNO(10)/10*0/
      INTEGER ISITE(50)/50*0/,ICGIM(50)/50*0/,PCOL
      CHARACTER TITLE*60,VNAMES*3(10),SNAMES*15(150),UNAMES*60(5)
      CHARACTER VDS*60(50),VST*2(50),SIFT*4(20),UIFT1*4(20),UNFT*4(20)
      CHARACTER PBM*3(150,10),UIFT2*4(20)
C
C
C READ INPUT PARAMETERS & VARIABLE DESCRIPTIONS
C
      READ(5,10)N,M,P,NVARS,TITLE
      READ(5,20) (VSNO(C),C=1,NVARS)
      READ(5,1) (SIFT(C),C=1,20)
      READ(5,1) (UIFT1(C),C=1,20)
      READ(5,1)  (UIFT2(C),C=1,20)
      READ(5,1) (UNFT(C),C=1,20)
      READ(5,40) (VNAMES(C),C=1,NVARS)
      READ(5,UNFT) (UNAMES(C),C=1,P)
      C=1
      WHILE (C .LE. M) DO
        READ(5,50)VST(C),VDS(C)
        C=C+1
      END WHILE
C
C PRINT INPUT PARAMETERS
C  (N.B. FMTS 180,190,200,250 MUST
C   BE CHANGED IF DIMENSIONS OF 'SITE'
C   OR 'CGIM' CHANGE)
C
      PRINT 110, TITLE
      PRINT 120
      R=C=1
      WHILE (C .LE. NVARS) DO
        PRINT 130, VNAMES(C)
        T=1
        WHILE (T .LE. VSNO(C)) DO
          PRINT 140, VST(R), VDS(R)
          T=T+1
```

```
          R=R+1
        END WHILE
        C=C+1
      END WHILE
C
C READ & PRINT SITE MATRIX & SNAMES
C
      PRINT 110, TITLE
      PRINT 170
      PRINT 180, (VNAMES(C),C=1,NVARS)
      PRINT 190, (VST(R),R=1,M)
      SROW =1
      WHILE (SROW .LE. N) DO
        READ(5,SIFT)SNAMES(SROW),(SITE(SROW,SCOL),SCOL=1,M)
        C=1
        WHILE (C .LE. M) DO
          ISITE(C)=IFIX(SITE(SROW,C))
          C=C+1
        END WHILE
        PRINT 200, SROW,(ISITE(C),C=1,M)
        IF (SROW/5 .EQ. FLOAT(SROW)/5.0) THEN DO
          PRINT 210
        END IF
        SROW=SROW+1
      END WHILE
      PRINT 110, TITLE
      PRINT 150
      C=1
      WHILE (C .LE. N) DO
        PRINT 160, C, SNAMES(C)
        C=C+1
      END WHILE
C
C READ & PRINT CGIM (USE MATRIX)
C
      PRINT 110, TITLE
      PRINT 220
      UPLN=1
      WHILE (UPLN .LE. P) DO
        PRINT 230, UNAMES(UPLN)
        PRINT 260, (VNAMES(C),C=1,NVARS)
        PRINT 190, (VST(R),R=1,M)
        UROW=1
        R=1
        WHILE (R .LE. NVARS) DO
          PRINT 240, VNAMES(R)
          T=1
          WHILE (T .LE. VSNO(R)) DO
            IF (UROW .LE. 35) THEN DO
              READ (5,UIFT1) (CGIM(UROW,UCOL),UCOL=1,UROW)
            ELSE DO
              READ (5,UIFT2) (CGIM(UROW,UCOL),UCOL=1,UROW)
            END IF
            C=1
```

```
         WHILE (C .LE. M) DO
           ICGIM(C)=IFIX(CGIM(UROW,C))
           C=C+1
         END WHILE
         PRINT 250, VST(UROW),(ICGIM(C),C=1,M)
         UROW=UROW+1
         T=T+1
       END WHILE
       R=R+1
     END WHILE
C
C CALL SUBROUTINE SINDEX & PRINT RESULTS
C
     CALL SINDEX(SITE,CGIM,NVARS,VNAMES,VSNO,N,M,PBM,SIDX)
C
     PRINT 100
     PRINT 290, UNAMES(UPLN)
     PRINT 270
     SROW=1
     WHILE (SROW .LE. N) DO
       PRINT 280,SROW,SNAMES(SROW),SIDX(SROW),(PBM(SROW,PCOL),
    *  PCOL=1,NVARS)
       SROW=SROW+1
     END WHILE
     UPLN=UPLN+1
   END WHILE
C
   PRINT 100
   STOP
C
C
C INPUT FORMATS
C
    1 FORMAT (20A4)
   10 FORMAT (I3,3(1X,I2),1X,A60)
   20 FORMAT (10I2)
   40 FORMAT (10(A3,1X))
   50 FORMAT (A2,1X,A60)
C
C
C OUTPUT FORMATS
C
  100 FORMAT ('1')
  110 FORMAT ('1',T35,A60//)
  120 FORMAT (' ',T35,'**LIST OF VARIABLES USED**'//
    *         '0',T20,'VARIABLE',T35,'CLASS',T49,'DESCRIPTION'//)
  130 FORMAT (' ',T22,A3)
  140 FORMAT (' ',T36,A2,T44,A60)
  150 FORMAT (' ',T35,'**SITE IDENTIFICATION**'//
    *         '0',T37,'NUMBER',T45,'DESCRIPTION')
  160 FORMAT (' ',T38,I3,T47,A15)
  170 FORMAT (' ',T35,'**SITE DESCRIPTION**')
  180 FORMAT ('-','NO.',T12,A3,T24,A3,T37,A3,T48,A3,T59,A3,T72,A3,
    *         T81,A3,T98,A3)
```

```
190 FORMAT ('0',T10,5A2,1X,6A2,1X,2(5A2,1X),6A2,1X,4A2,1X,7A2,1X,
     *        6A2,1X)
200 FORMAT (' ',1X,I3,T10,5I2,1X,6I2,1X,2(5I2,1X),6I2,1X,4I2,1X,
     *        7I2,1X,6I2,1X)
210 FORMAT (' ')
220 FORMAT ('-',T35,'**CROP INTERACTION MATRICES**'/)
230 FORMAT (' ',T30,'CROP GROUP: ',A60/)
240 FORMAT ('0',4X,A3)
250 FORMAT (' ',1X,A2,T10,5I2,1X,6I2,1X,2(5I2,1X),6I2,1X,4I2,1X,
     *        7I2,1X,6I2,1X)
260 FORMAT (' ',T10,A3,T24,A3,T37,A3,T48,A3,T59,A3,T72,A3,
     *        T81,A3,T98,A3)
270 FORMAT ('-',T10,'SITE NO.',T22,'SITE NAME',T47,'SIDX',T60,
     *        'PROBLEM FACTORS')
280 FORMAT ('0',//,T10,I3,T22,A15,T47,F5.1,T60,8(A3,1X))
290 FORMAT ('0','**LAND SUITABILITY INDICES FOR: ',A60,'**')
C
      END
C
      SUBROUTINE SINDEX(SITE,USE,NVARS,VNAMES,VSNO,N,M,PBM,SIDX)
C
C     SINDEX CALCULATES SUITABILITY INDICES AND PINPOINTS POSSIBLE
C     PROBLEM OR LIMITING LAND FACTORS FOR UP TO 5 USES OVER 150 SITES.
C
C     SINDEX IS ACTIVATED BY THE COMMAND:
C     "CALL SINDEX(SITE, USE, NVARS,VNAMES,VSNO,N,M,PBM,SIDX)" WHERE:
C         SITE= INPUT REAL 2-DIM. ARRAY OF SITES VS. SITE DESCRIPTIONS
C               DEFINED BY A MAXIMUM OF 10 VARIABLES, 50 VARIABLE STATES
C               IN BINARY FORMAT. N.B. ONLY 1 VARIABLE STATE PER VARIABLE
C               PER SITE ALLOWED TO EQUAL 1 (IE PRESENT AT SITE)
C         USE= INPUT REAL 2-DIM. ARRAY WHICH EQUALS RATINGS
C              AND INTERACTIONS OF POSSIBLE SITE VARIABLES FOR 1 USE.
C              RATING RANGE FROM 1 TO 5 (5=EXCEL., 4=GOOD, 3=MEDIOCRE,
C              2=POOR,1=UNSUITED); MAX. OF 5 USES ALLOWED.
C         NVARS= INPUT INTEGER, NUMBER OF VARIABLES (LAND FACTORS) UP TO
C                A MAXIMUM OF 10.
C         VNAMES= INPUT CHARACTER VECTOR, LENGTH NVARS, EACH ENTRY EQUALS
C                 A 3 CHARACTER VARIABLE NAME.
C         VSNO= INPUT INTEGER VECTOR, LENGTH NVARS, EACH ENTRY EQUALS NO.
C               OF VARIABLE STATES OF VARIABLE AT VSNO(C).
C         N= INPUT INTEGER, EQUALS NO. ROWS OF SITE MATRIX, IE. NO. SITES
C            ASSESSED.
C         M= INPUT INTEGER, EQUALS NO COLS SITE MATRIX, NO. ROWS AND COLS
C            3-D ARRAY EQUALS TOTAL NO. VARIABLE STATES, MAX. = 50
C         PBM= OUTPUT CHARACTER 2-D ARRAY OF POSSIBLE PROBLEM LAND FACTORS
C              PER USE AT EACH SITE: PBM(SROW,SCOL) WHERE: SROW=SITE,
C              PCOL=PBM'S AT SITE FOR USE. 1 MATRIX PER USE CREATED.
C         SIDX= OUTPUT REAL MATRIX OF SUITABILITY INDICES: SIDX(SROW,UPLN)
C
C      RESULTS ARE RETURNED TO MAIN PROGRAM FOR PRINTING & FURTHER MANIPULA
C
C
C DECLARATION AND INITIALIZATION OF VARIABLES
C
```

```
      INTEGER UPLN,SROW,UROW,PCOL,SCOL,C,X,NVARS,VSNO(10),N,M
      REAL SUM,TEST,ISUM,IVEC(150,50),SITE(150,50),USE(50,50),SIDX(15
      CHARACTER PBM*3(150,10),VNAMES*3(10)
C
C
C COMPUTE IVECTORS AND CHECK FOR POSSIBLE LAND FACTOR LIMITATIONS
C
          SROW=1
          WHILE (SROW .LE. N) DO
            UROW=PCOL=1
            WHILE (UROW .LE. M) DO
              SCOL=1
              SUM=0
              WHILE (SCOL .LE. M) DO
                SUM=SUM+(SITE(SROW,SCOL)*USE(SCOL,UROW))
                IF (SCOL .EQ. UROW) THEN DO
                  TEST=SITE(SROW,SCOL)*USE(SCOL,UROW)
                  IF (TEST .NE. 0) THEN DO
                    IF (TEST .LE. 2.0) THEN DO
                      C=1
                      X=0
 11                   CONTINUE
                      WHILE (C .LE. NVARS) DO
                        IF ((VSNO(C)+X) .LT. SCOL) THEN DO
                          X=X+VSNO(C)
                          C=C+1
                          GO TO 11
                        END IF
                        GO TO 12
                      END WHILE
 12                   CONTINUE
                      PBM(SROW,PCOL)=VNAMES(C)
                      PCOL=PCOL+1
                    END IF
                  END IF
                END IF
                SCOL=SCOL+1
              END WHILE
              IVEC(SROW,UROW)=SUM
              UROW=UROW+1
            END WHILE
            SROW=SROW+1
          END WHILE
C
C
C COMPUTE SUITABILITY INDICES (SIDX) AT EACH SITE ((SROW,SCOL),COL=1,
C FOR EACH USE ((CGIM(UROW,UCOL,UPLN),UPLN=1,P))
C
          SROW=1
          WHILE (SROW .LE. N) DO
            ISUM=0
            SCOL=1
            WHILE (SCOL .LE. M) DO
              ISUM=ISUM+(SITE(SROW,SCOL)*IVEC(SROW,SCOL))
```

```
          SCOL=SCOL+1
        END WHILE
        SIDX(SROW)=ISUM
        SROW=SROW+1
      END WHILE
C
     RETURN
     END
```

The detection of limiting factors is made by means of a flexible algorithm which operates in the following manner. While each entry of n[I]m is being computed a check is made to see if variable state a(i,j) of n[S]m is indeed present in site k. If present then the algorithm determines whether the rating given to a(i,j) by the appropriate entry of m[U]m is above or below a specified critical threshold value called "TEST". In this version of LASTAN the value TEST equals 2. If the rating is greater than TEST then the algorithm exits because no limiting factor was found. However, if the rating is less than or equal to TEST then the name of the variable state and the variable in question are recorded, stored, and later printed out as potentially limiting factors.

## Appendix G

## DATA, 145[S]44 AND 44[U]44

### Map Delineation Description: 145[S]44

| SITE | SPH | TEX | DEP | DRA | SLO | STO | PPP | KKK |
|---|---|---|---|---|---|---|---|---|
| C1/3.3 | 00100 | 001000 | 01000 | 01000 | 010000 | 1000 | 1000000 | 010000 |
| C2/2.3 | 00100 | 010000 | 01000 | 00100 | 010000 | 1000 | 0100000 | 000100 |
| C2/3.2 | 00100 | 001000 | 01000 | 00100 | 100000 | 1000 | 1000000 | 010000 |
| C2/3.3 | 00100 | 001000 | 01000 | 00100 | 010000 | 1000 | 1000000 | 010000 |
| C3/2.2 | 01000 | 010000 | 01000 | 00100 | 100000 | 1000 | 0100000 | 000010 |
| C4-D3/3.2* | 01000 | 001000 | 01000 | 00010 | 100000 | 1000 | 0100000 | 000100 |
| C5/3.2 | 00010 | 001000 | 01000 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| CH1/3.2 | 00010 | 001000 | 00010 | 01000 | 100000 | 1000 | 1000000 | 000100 |
| CH1/3/4.0 | 00010 | 001000 | 00010 | 01000 | 100000 | 1000 | 1000000 | 000100 |
| CH1-G1/3.2 | 00010 | 001000 | 00001 | 01000 | 100000 | 0100 | 1000000 | 000100 |
| D1/3.2 | 01000 | 001000 | 00010 | 00100 | 100000 | 1000 | 0100000 | 000001 |
| D1/4.2 | 01000 | 000100 | 00010 | 00100 | 100000 | 1000 | 0100000 | 000001 |
| D1/4.3 | 01000 | 000100 | 00010 | 00100 | 010000 | 1000 | 0100000 | 000001 |
| D2/3.2 | 01000 | 001000 | 00010 | 00100 | 100000 | 1000 | 1000000 | 001000 |
| D2/4.0 | 00010 | 000100 | 00010 | 00100 | 100000 | 1000 | 1000000 | 000010 |
| D3.0/0.1 | 00010 | 000001 | 01000 | 00001 | 100000 | 1000 | 1000000 | 010000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| D3/3.1 | 00010 | 001000 | 00010 | 00010 | 100000 | 0100 | 0100000 | 000100 |
| D3/3.1/2 | 00010 | 001000 | 00010 | 00010 | 100000 | 0100 | 0100000 | 000100 |
| D3/3/4.1 | 00010 | 000100 | 00010 | 00010 | 100000 | 0100 | 0100000 | 000100 |
| D3/3/4.2 | 00010 | 000100 | 00010 | 00010 | 100000 | 0100 | 0100000 | 000100 |
| D3/4.1 | 00010 | 000100 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| D3/4.1/2 | 00100 | 000100 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000010 |
| D3-C4/2.2 | 00100 | 010000 | 00100 | 00010 | 100000 | 1000 | 0100000 | 000100 |
| D3-NG2/3/4.2 | 00010 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 001000 |
| F1.P/3.2 | 00001 | 001000 | 10000 | 01000 | 100000 | 0001 | 1000000 | 010000 |
| F1.P/3.3 | 00001 | 001000 | 10000 | 01000 | 010000 | 0001 | 1000000 | 010000 |
| F1.P/3.4 | 00001 | 001000 | 10000 | 01000 | 001000 | 0001 | 1000000 | 010000 |
| F5/2.2 | 00001 | 010000 | 10000 | 00100 | 100000 | 0010 | 1000000 | 001000 |
| F5.P/3.2 | 00010 | 001000 | 10000 | 00100 | 100000 | 0001 | 1000000 | 001000 |
| G1/2.2 | 00010 | 010000 | 00010 | 01000 | 100000 | 0100 | 0100000 | 000100 |
| G1/2.3 | 00010 | 010000 | 00010 | 01000 | 010000 | 0100 | 0100000 | 000100 |
| G1/2/3.2 | 00100 | 010000 | 00010 | 01000 | 100000 | 0100 | 1000000 | 010000 |
| G1.S/2.2 | 00010 | 010000 | 10000 | 01000 | 100000 | 0100 | 1000000 | 100000 |
| G1.P/2.3 | 00100 | 010000 | 01000 | 01000 | 010000 | 0010 | 0100000 | 010000 |
| G1/2/3.3 | 00100 | 010000 | 00010 | 01000 | 010000 | 0100 | 1000000 | 010000 |
| G1/2.2/3 | 00100 | 010000 | 00010 | 01000 | 010000 | 0010 | 1000000 | 100000 |
| G1/2.4 | 00010 | 010000 | 00010 | 01000 | 001000 | 0100 | 1000000 | 010000 |
| G1/2.3/4 | 00010 | 010000 | 00010 | 01000 | 001000 | 0100 | 1000000 | 010000 |
| G1.SP/2.4 | 00010 | 010000 | 01000 | 01000 | 001000 | 0001 | 0100000 | 010000 |
| G1.P/2.4 | 00010 | 010000 | 00010 | 01000 | 001000 | 0001 | 0100000 | 000100 |
| G1/3.2 | 00010 | 001000 | 00010 | 01000 | 100000 | 0100 | 1000000 | 010000 |
| G1/3.3 | 00010 | 001000 | 00010 | 01000 | 010000 | 0100 | 1000000 | 010000 |
| G1/3.4 | 00010 | 001000 | 00010 | 01000 | 001000 | 0100 | 1000000 | 010000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G1/3.6 | 00010 | 001000 | 00010 | 01000 | 000010 | 1000 | 1000000 | 010000 |
| G1/3.2/3* | 00010 | 001000 | 00010 | 01000 | 010000 | 0100 | 1000000 | 010000 |
| G1.P/2.2/3 | 00100 | 010000 | 00010 | 01000 | 100000 | 0001 | 0100000 | 010000 |
| G1.P/3.2/3 | 00010 | 001000 | 00010 | 01000 | 100000 | 0001 | 0100000 | 010000 |
| G1.P/3.2 | 00010 | 001000 | 00010 | 01000 | 100000 | 0001 | 1000000 | 010000 |
| G1.P/3.3 | 00010 | 001000 | 00010 | 01000 | 010000 | 0001 | 1000000 | 010000 |
| G1.P/3.4 | 00010 | 001000 | 00010 | 01000 | 001000 | 0001 | 1000000 | 010000 |
| G1-D3/3/4.2 | 00010 | 001000 | 00001 | 00100 | 100000 | 1000 | 1000000 | 001000 |
| G1.P-O1.P/2.3 | 00100 | 010000 | 00010 | 01000 | 010000 | 0001 | 0100000 | 001000 |
| G1.P-O1.P/2.4 | 00100 | 010000 | 00010 | 01000 | 001000 | 0001 | 0100000 | 001000 |
| G2/2.2 | 00001 | 010000 | 00010 | 01000 | 100000 | 0100 | 1000000 | 100000 |
| G2/3.2 | 00001 | 001000 | 00010 | 01000 | 100000 | 0100 | 1000000 | 100000 |
| G2.P/2.2 | 00001 | 010000 | 00010 | 01000 | 100000 | 0001 | 1000000 | 100000 |
| G2.P/3.2 | 00001 | 001000 | 00010 | 01000 | 100000 | 0001 | 1000000 | 100000 |
| G2-P4/3.2 | 00010 | 001000 | 00010 | 00100 | 100000 | 0100 | 0100000 | 010000 |
| G2-P2/3.2* | 00010 | 001000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 001000 |
| G2-NG2/3.2 | 00001 | 001000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 010000 |
| G3/2.2 | 00010 | 010000 | 00010 | 00010 | 100000 | 0010 | 1000000 | 010000 |
| G3/3.2 | 00010 | 001000 | 00010 | 00010 | 100000 | 0010 | 1000000 | 010000 |
| G3.SP/3.2 | 00010 | 001000 | 10000 | 00010 | 100000 | 0001 | 1000000 | 010000 |
| G4/2.2 | 00001 | 010000 | 00010 | 01000 | 100000 | 0100 | 1000000 | 000100 |
| G4/3.0 | 00100 | 001000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 000010 |
| G4/3.2 | 00100 | 001000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 000010 |
| G4/3.2* | 00100 | 001000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 000010 |
| G4/3.3 | 00100 | 001000 | 00010 | 00100 | 010000 | 0100 | 1000000 | 000010 |
| G4/3.3* | 00100 | 001000 | 00010 | 00100 | 010000 | 0100 | 1000000 | 000010 |
| G5/2.2 | 00010 | 010000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 100000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G5/3.2 | 00001 | 001000 | 00010 | 00100 | 100000 | 0100 | 1000000 | 001000 |
| H3/B.0 | 00100 | 000001 | 00100 | 00001 | 100000 | 1000 | 1000000 | 000100 |
| H3.S/B.0 | 00100 | 000001 | 10000 | 00001 | 100000 | 1000 | 1000000 | 000100 |
| H3.S/A.2 | 00100 | 000001 | 10000 | 00001 | 100000 | 1000 | 1000000 | 000100 |
| H4/O.1 | 00010 | 000001 | 00100 | 00001 | 100000 | 1000 | 1000000 | 001000 |
| I2/2.2 | 00001 | 010000 | 00010 | 00100 | 100000 | 1000 | 1000000 | 100000 |
| J2.V-J1/2.3 | 00010 | 010000 | 00100 | 01000 | 010000 | 1000 | 1000000 | 100000 |
| J3-U2/1/2.2 | 00010 | 100000 | 00010 | 00100 | 100000 | 1000 | 1000000 | 000100 |
| J4/2.2 | 00100 | 010000 | 00100 | 00001 | 100000 | 1000 | 0100000 | 001000 |
| J4.V/1/2.2 | 00100 | 100000 | 00100 | 00010 | 100000 | 1000 | 0100000 | 010000 |
| J5/2.1 | 00010 | 010000 | 00100 | 00001 | 100000 | 1000 | 1000000 | 100000 |
| J5/2.2 | 00010 | 010000 | 00100 | 00001 | 100000 | 1000 | 1000000 | 100000 |
| J5-P4/2/3.1 | 00100 | 010000 | 00100 | 00001 | 100000 | 1000 | 1000000 | 100000 |
| J6.O/0.2 | 00010 | 000001 | 00100 | 00001 | 100000 | 1000 | 1000000 | 010000 |
| K1/1.2 | 00100 | 100000 | 00010 | 10000 | 100000 | 0010 | 0000100 | 100000 |
| K1/1.2/3 | 00100 | 100000 | 00010 | 10000 | 100000 | 0010 | 0000100 | 100000 |
| K1/1.3/4* | 00100 | 100000 | 00010 | 10000 | 010000 | 0010 | 0000100 | 100000 |
| K1/1.3 | 00100 | 100000 | 00010 | 10000 | 010000 | 0010 | 0000100 | 100000 |
| K1/2.4 | 00001 | 010000 | 00010 | 10000 | 001000 | 0010 | 0000100 | 000100 |
| K1/3.4 | 00100 | 001000 | 00010 | 01000 | 001000 | 0010 | 0010000 | 001000 |
| K2.O/0.2 | 00100 | 000001 | 01000 | 00010 | 100000 | 1000 | 0001000 | 001000 |
| M3/2.2 | 00100 | 010000 | 00100 | 00100 | 100000 | 1000 | 1000000 | 010000 |
| M3/3.2 | 00100 | 001000 | 00100 | 00100 | 100000 | 1000 | 1000000 | 010000 |
| M6-D3/2.2 | 00010 | 010000 | 00100 | 00010 | 100000 | 1000 | 1000000 | 010000 |
| ML2/1.3 | 00100 | 100000 | 00100 | 01000 | 010000 | 1000 | 1000000 | 010000 |
| N1/3.3 | 00010 | 001000 | 10000 | 10000 | 010000 | 0010 | 1000000 | 010000 |
| N1.P- 4/2.4 | 00010 | 010000 | 10000 | 10000 | 001000 | 0001 | 1000000 | 001000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NG1/3.2 | 00010 | 001000 | 00010 | 00100 | 100000 | 1000 | 1000000 | 000100 |
| NG1/3.1/2 | 00010 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG1-G2/3.2/3 | 00100 | 001000 | 00010 | 00100 | 010000 | 1000 | 1000000 | 010000 |
| NG2/1.2 | 01000 | 100000 | 00010 | 00010 | 100000 | 1000 | 0010000 | 001000 |
| NG2/3.0 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG2/3.1 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG2/3.2 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG2/3/4.2 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG2-P4/3.1/2 | 00001 | 001000 | 00100 | 00010 | 100000 | 1000 | 0100000 | 001000 |
| NG2.V-J5/2.2 | 00010 | 010000 | 00100 | 00100 | 100000 | 1000 | 1000000 | 010000 |
| NG2/3/4.1 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG2-G3/3.1 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| NG3/3.2 | 00010 | 001000 | 00010 | 00100 | 100000 | 1000 | 0100000 | 000010 |
| NG3/3.3 | 00010 | 001000 | 00010 | 00100 | 010000 | 1000 | 0100000 | 000010 |
| NG3-M3/3.2 | 00010 | 001000 | 00010 | 00100 | 100000 | 1000 | 0100000 | 000010 |
| O1.P/2.3 | 00100 | 010000 | 00001 | 10000 | 010000 | 0001 | 1000000 | 001000 |
| O1.P/2.3/4 | 00100 | 010000 | 00001 | 10000 | 010000 | 0001 | 1000000 | 001000 |
| O1.P/2.4 | 00100 | 010000 | 00001 | 10000 | 001000 | 0001 | 1000000 | 001000 |
| O1.P-G1/.P/2.4 | 00100 | 010000 | 00001 | 01000 | 001000 | 0001 | 0100000 | 001000 |
| O1-U1/1.3 | 00100 | 100000 | 00001 | 10000 | 010000 | 0010 | 0010000 | 100000 |
| P2/3.2 | 00100 | 001000 | 00100 | 00100 | 100000 | 1000 | 1000000 | 000100 |
| P3/3.2 | 00010 | 001000 | 00100 | 00100 | 100000 | 1000 | 1000000 | 001000 |
| P4/3.1 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 0010000 | 001000 |
| P4/3.1/2 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 0010000 | 001000 |
| P4/3.2 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 0010000 | 001000 |
| P4-J4/2.2 | 01000 | 010000 | 00100 | 00010 | 100000 | 1000 | 1000000 | 100000 |
| P4-U8/3/2.2 | 00100 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 100000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P4-J5/2.2 | 00100 | 010000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 100000 |
| P4-G2/3.2 | 00100 | 001000 | 00010 | 00010 | 100000 | 1000 | 0100000 | 010000 |
| Q1.SP/2.3 | 00100 | 010000 | 10000 | 01000 | 010000 | 0001 | 0100000 | 000010 |
| R2/3.3 | 00010 | 001000 | 00010 | 00010 | 010000 | 1000 | 0010000 | 000100 |
| R3/3.2 | 00001 | 001000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 000100 |
| R3/4.1 | 00100 | 000100 | 00010 | 00010 | 100000 | 1000 | 0100000 | 000010 |
| R3/4.1/2 | 00100 | 000100 | 00010 | 00010 | 100000 | 1000 | 0100000 | 000010 |
| U1/1.2 | 00100 | 100000 | 00001 | 10000 | 100000 | 1000 | 0001000 | 100000 |
| U1/1.3 | 00100 | 100000 | 00001 | 10000 | 010000 | 1000 | 0001000 | 100000 |
| U1/1.3* | 00100 | 100000 | 00001 | 10000 | 010000 | 1000 | 0001000 | 100000 |
| U1/1.4 | 00100 | 100000 | 00001 | 10000 | 001000 | 1000 | 0001000 | 100000 |
| U2/1.2 | 00100 | 100000 | 00001 | 01000 | 100000 | 1000 | 1000000 | 001000 |
| U2/2.2 | 00010 | 010000 | 00001 | 01000 | 100000 | 1000 | 0100000 | 100000 |
| U5/1.2 | 00100 | 100000 | 00001 | 00100 | 100000 | 0100 | 1000000 | 001000 |
| U7/1.2 | 00100 | 100000 | 00010 | 00100 | 100000 | 1000 | 0000100 | 000010 |
| U7/1.2* | 00100 | 100000 | 00010 | 00100 | 100000 | 1000 | 0000100 | 000010 |
| U13/1.2 | 01000 | 100000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 100000 |
| U13/1/2.2 | 01000 | 100000 | 00010 | 00010 | 100000 | 1000 | 1000000 | 100000 |
| U13.P/1.2 | 01000 | 100000 | 00010 | 00010 | 100000 | 0001 | 1000000 | 100000 |
| U14.0/0.1/2 | 00100 | 000001 | 00010 | 00001 | 100000 | 1000 | 0010000 | 001000 |
| U14.0/0.1 | 00100 | 000001 | 00010 | 00001 | 100000 | 1000 | 0010000 | 001000 |

## Crop Group "A" Ratings and Interactions:

m[ U ]m

3

0 5

0 0 5

0 0 0 5

0 0 0 0 4

0-2-2-2 0 2

-1 1 1 2 0 0 5

0 1 1 2 0 0 0 5

0 1 1 1 0 0 0 0 5

-2 0 0 0 0 0 0 0 0 4

-1-3-3-3-2 0 0 0 0 0 2

-2-4-4-4-3-1-4-4-4-3-1 2

0 0 0 0 1 0 0 0-1 0 0 0 4

0 1 1 1 0-1 1 1 1 0-1 0 0 5

0 1 1 1 0-1 1 1 1 0-1 0 0 0 5

0 1 1 1 0-1 1 1 1 0-1 0 0 0 0 5

1-1-1-1-2 1 0 0-1 0 0-2 0 0 0 0 3

-1 1 1 1-1 1 1 1 1 0-1-2 0 1 1 1 0 5

0-1-1 1-1 1 0 0 1 0-1-2 0 0 0 0 0 0 4

-1 0 0 0-1 1 0 1 1 0 0-1 1 1 1 1 0 0 0 2

0-2-2-2-1 0-2-2-2-1 0 0 0-2-2-2 0 0 0 0 1

-1 1 1 1 0-1 1 1 1 0-2-4 0 1 1 1 0 1 1 0-2 5

-1 1 1 1 0-1 1 1 1 0-2-4 0 1 1 1 0 0 0 0-1 0 4

1-1-1-1 0 0 0 0-1 0-1-3 1 0 0 0 1 0 0 0 0 0 0 3

1-1-1-1 0 0 1 1 0 0 0-2 0 0 0 0 2 0-2-2-1 0 0 0 2

-1-3-3-3-2 1 0 0-1-1-2-1 0-1-1-1 0-1-2-1 0 0 0 0 0 1

-1-4-4-4-3 0-2-2-3-3-1 0-2-3-3-3 0-2-2 0 0 0 0 0 0 0 1

0 0 0 0 0-1 0 0 0 0-2-4 0 0 0 0 1 0 0 0-2 0 0 0 0-1-3 5

0 0 0 0 0-1 0 0 0 1-2-4 0 0 0 0 0 0 0 0-2 0 0 0 0-1-3 0 5

-1-2-2-2-1 1-1-1-1-1 0-1 0-1-1-1 0-1-1 0 0 0 0 0 0 1 0 0 0 2

-1-3-3-3-2 0-2-2-2-1 0 0-2-3-3-3-1-3-2 0 0-3-3-2-1 0 0 0 0 0 1

-2 0 0 0-2 0 1 1 1 0 0-2 2 2 2 2 0 1 0 1 1 1 1 2 1 0-1 1 1 0-1 3

1 0 0 0 0 0 0 0 0 0-1-3 1 1 1 1 0 0 1 1-1 0 0 0 0-1-2 0 0 0-2 0 4

1 0 0 0 0 0 0 0 0 0-2-4 0 0 0 0 0 0 0 0-2 0 0 0-1-2-3 0 0-1-3 0 0 5

1 0 0 0 0 0 0 0 0 0-2-4 1 0 0 0 0 0 0 0-2 0 0 0-1-2-3 0 0-1-3 0 0 0 5

1 0 0 0 0 1 0 0 0 0-2-4 1 0 0 0 0 0 0 0-2 0 0 0-1-2-3 0 0-1-3 0 0 0 0

5

1 1 1 1 0 2 1 1 0 1-1-2 2 1 1 1 1 0 1 1 1 1 1 2 1 0-1 1 1 0-1 0 0 0 0

0 3

1 0 0 0 0 1 0 0 0 0-1-2 1 0 0 0 1 0 0 1 1 0 0 1 0 0-1 0 0 0-1 0 0 0 0

0 0 3

-2 0 0 1-2 0 1 1 1 1 0-1 2 1 1 1 0 1 0 0 0 1 1 2 1 0-1 1 1 0-1 1 1 1 1

1 1 2 3

1 0 0 0 0 0 0 0 0 0 0-2 1 0 0 0 0 0 0 0-1 0 0 1 0 0-2 0 0 0-2 0 0 0 0

0 0 1 0 4

1 0 0 0 1 0 0 0 0 0 0-3 1 0 0 0 0 0 0 0-1 0 0 1 0 0-2 0 0 0-2 0 0 0 0

0 1 1 0 0 4

1 0 0 0 0 0 0 0 0 0 0-1-3 0 0 0 0 0 0-1-1-2 0 0 0-1-1-3 0 0-1-3 0 1 0 0

0 1 0 0 0 0 5

1 0 0 0 0 1 0 0 0 0-1-3 1 0 0 0 0 0-1-1-2 0 0 0-1-1-3 0 0-1-3 0 1 0 0

0 1 1 0 0 0 0 5

1 0 0 0 0 0 0 0 0 0-1-1 1 0 0 0 2 0 2 1 2 1 1 1 1 0-1 0 0 0-1 1 2 1 1

1 3 3 0 0 0 0 0 3

## Appendix H

## OUTPUT FROM LASTAN WITH SUITABILITY AND CAPABILITY CLASSES ADDED

**LAND SUITABILITY INDICES FOR: BARLEY, PEAS, SOY, RYE, BEANS, RADISHES**

N.B. A '*' beside a SITE NO. means the LASTAN index (SIDX) for this site is an anomaly.

| SITE NO. | SITE NAME | SIDX | SCLASS | PROBLEM FACTORS | CAPABILITY |
|---|---|---|---|---|---|
| 1 | C1/3.3 | 47.0 | 2 | UUU UUU UUU UUU | 2Fv(t) |
| 2 | C2/2.3 | 40.0 | 3 | UUU UUU UUU UUU | 2Fw(t) |
| 3 | C2/3.2 | 44.0 | 2 | UUU UUU UUU UUU | 2fw |
| 4 | C2/3.3 | 42.0 | 2 | UUU UUU UUU UUU | 2fw(t) |
| 5 | C3/2.2 | 43.0 | 2 | UUU UUU UUU UUU | 2Fw(t) |
| 6 | C4-D3/3.2* | 42.0 | 2 | DRA UUU UUU UUU | 2W(v)f |
| 7 | C5/3.2 | 45.0 | 2 | DRA UUU UUU UUU | 2W |
| 8 | CH1/3.2 | 55.0 | 1 | UUU UUU UUU UUU | 1w |
| 9 | CH1/3/4.0 | 55.0 | 1 | UUU UUU UUU UUU | 1w-1p |
| 10 | CH1-G1/3.2 | 55.0 | 1 | UUU UUU UUU UUU | 1w |
| 11 | D1/3.2 | 49.0 | 2 | UUU UUU UUU UUU | 1w |
| 12 | D1/4.2 | 50.0 | 2 | UUU UUU UUU UUU | 1w(t) |
| 13 | D1/4.3 | 48.0 | 2 | UUU UUU UUU UUU | 1wv |
| 14 | D2/3.2 | 47.0 | 2 | UUU UUU UUU UUU | 2wv |

| | | | | |
|---|---|---|---|---|
| 15 | D2/4.0 | 50.0 | 2 | UUU UUU UUU UUU 2Wv |
| 16* | D3.0/0.1 | 22.0 | 5 | TEX DRA UUU UUU 2Wi |
| 17 | D3/3.1 | 47.0 | 2 | DRA UUU UUU UUU 2W |
| 18 | D3/3.1/2 | 47.0 | 2 | DRA UUU UUU UUU 2W |
| 19 | D3/3/4.1 | 46.0 | 2 | DRA UUU UUU UUU 2W |
| 20 | D3/3/4.2 | 46.0 | 2 | DRA UUU UUU UUU 2W |
| 21 | D3/4.1 | 48.0 | 2 | DRA UUU UUU UUU 2W |
| 22 | D3/4.1/2 | 48.0 | 2 | DRA UUU UUU UUU 2W |
| 23 | D3-C4/2.2 | 45.0 | 2 | DRA UUU UUU UUU 2W-3W |
| 24 | D3-NG2/3/ 4.2 | 49.0 | 2 | DRA UUU UUU UUU 2W |
| 25* | F1.P/3.2 | 2.0 | 7 | DEP STO UUU UUU 5R*P* |
| 26* | F1.P/3.3 | 0.0 | 7 | DEP STO UUU UUU 5R*P* |
| 27 | F1.P/3.4 | 2.0 | 7 | DEP STO UUU UUU 7R*P*T* |
| 28 | F5/2.2 | 9.0 | 7 | DEP STO UUU UUU 7R*P*W(v) |
| 29 | F5.P/3.2 | 5.0 | 7 | DEP STO UUU UUU 7R*P*Wv |
| 30 | G1/2.2 | 52.0 | 1 | UUU UUU UUU UUU 1p |
| 31 | G1/2.3 | 50.0 | 1 | UUU UUU UUU UUU 2pt |
| 32 | G1/2/3.2 | 53.0 | 1 | UUU UUU UUU UUU 1p |
| 33* | G1.S/2.2 | 29.0 | 4 | DEP UUU UUU UUU 3RP |
| 34 | G1.P/2.3 | 36.0 | 3 | STO UUU UUU UUU 3Rpt |
| 35 | G1/2/3.3 | 51.0 | 1 | UUU UUU UUU UUU 2pt |
| 36 | G1/2.2/3 | 46.0 | 2 | STO UUU UUU UUU 1p |
| 37 | G1/2.4 | 49.0 | 2 | UUU UUU UUU UUU 2Tp |
| 38 | G1/2.3/4 | 49.0 | 2 | UUU UUU UUU UUU 2pt |
| 39 | G1.SP/2.4 | 22.0 | 5 | STO UUU UUU UUU 5P*RT |
| 40* | G1.P/2.4 | 23.0 | 5 | STO UUU UUU UUU 4P*T |

| | | | | | |
|---|---|---|---|---|---|
| 41 | G1/3.2 | 54.0 | 1 | UUU UUU UUU UUU | 1p |
| 42 | G1/3.3 | 52.0 | 1 | UUU UUU UUU UUU | 2pt |
| 43 | G1/3.4 | 49.0 | 2 | UUU UUU UUU UUU | 2Tp |
| 44 | G1/3.6 | 39.0 | 3 | SLO UUU UUU UUU | 3T*p |
| 45 | G1/3.2/3* | 52.0 | 1 | UUU UUU UUU UUU | 1p |
| 46* | G1.P/2.2/3 | 27.0 | 4 | STO UUU UUU UUU | 3P* |
| 47* | G1.P/3.2/3 | 28.0 | 4 | STO UUU UUU UUU | 3P* |
| 48* | G1.P/3.2 | 32.0 | 4 | STO UUU UUU UUU | 3P* |
| 49* | G1.P/3.3 | 30.0 | 4 | STO UUU UUU UUU | 3P* |
| 50 | G1.P/3.4 | 28.0 | 4 | STO UUU UUU UUU | 4P*t |
| 51 | G1-D3/3/4.2 | 50.0 | 2 | UUU UUU UUU UUU | 1p-2w |
| 52* | G1.P-01.P/ 2.3 | 25.0 | 5 | STO UUU UUU UUU | 3P*t-5P*MPt |
| 53* | G1.P-01.P/ 4.2 | 22.0 | 5 | STO UUU UUU UUU | 4P*T-5P*MPT |
| 54 | G2/2.2 | 48.0 | 2 | UUU UUU UUU UUU | 2pw |
| 55 | G2/3.2 | 48.0 | 2 | UUU UUU UUU UUU | 2pw |
| 56* | G2.P/2.2 | 27.0 | 4 | STO UUU UUU UUU | 3P*w |
| 57* | G2.P/3.2 | 27.0 | 4 | STO UUU UUU UUU | 3P*w |
| 58 | G2-P4/3.2 | 48.0 | 2 | UUU UUU UUU UUU | 2pw-2wf |
| 59 | G2-P2/3.2* | 50.0 | 2 | UUU UUU UUU UUU | 2pw-2fwv |
| 60 | G2-NG2/3.2 | 41.0 | 2 | UUU UUU UUU UUU | 2pt |
| 61 | G3/2.2 | 40.0 | 3 | DRA STO UUU UUU | 3W*p |
| 62 | G3/3.2 | 41.0 | 2 | DRA STO UUU UUU | 3W*p |
| 63 | G3.SP/3.2 | 7.0 | 7 | DEP DRA STO UUU | 7W*P*R |
| 64 | G4/2.2 | 46.0 | 2 | UUU UUU UUU UUU | 2pv |
| 65 | G4/3.0 | 47.0 | 2 | UUU UUU UUU UUU | 2pv |

| | | | | | |
|---|---|---|---|---|---|
| 66 | G4/3.2 | 47.0 | 2 | UUU UUU UUU UUU | 2pv |
| 67 | G4/3.2* | 47.0 | 2 | UUU UUU UUU UUU | 2pv |
| 68 | G4/3.3 | 45.0 | 2 | UUU UUU UUU UUU | 2pvt |
| 69 | G4/3.3* | 45.0 | 2 | UUU UUU UUU UUU | 2pvt |
| 70 | G5/2.2 | 55.0 | 1 | UUU UUU UUU UUU | 3Wvp |
| 71 | G5/3.2 | 42.0 | 2 | UUU UUU UUU UUU | 3Wvp |
| 72 | H3/B.0 | 20.0 | 5 | TEX DRA UUU UUU | Not rated |
| 73 | H3.S/B.0 | -2.0 | 7 | TEX DEP DRA UUU | " " |
| 74 | H3.S/A.2 | -2.0 | 7 | TEX DEP DRA UUU | " " |
| 75 | H4/0.1 | 21.0 | 5 | TEX DRA UUU UUU | " " |
| 76 | I2/2.2 | 43.0 | 2 | UUU UUU UUU UUU | 3F*v |
| 77* | J2.V-J1/2.3 | 58.0 | 1 | UUU UUU UUU UUU | 4Fwt-4F*vt |
| 78* | J3-U2/1/2.2 | 38.0 | 3 | TEX UUU UUU UUU | 4F*Wv-4F*v |
| 79 | J4/2.2 | 29.0 | 4 | DRA UUU UUU UUU | 4W*(v)F |
| 80 | J4.V/1/2.2 | 34.0 | 4 | TEX DRA UUU UUU | 4W*(v)F |
| 81* | J5/2.1 | 41.0 | 2 | DRA UUU UUU UUU | 4W*F |
| 82* | J5/2.2 | 41.0 | 2 | DRA UUU UUU UUU | 4W*F |
| 83* | J5-P4/2/3.1 | 39.0 | 3 | DRA UUU UUU UUU | 4W*F-3WF |
| 84 | J6.0/0.2 | 21.0 | 5 | TEX DRA UUU UUU | 5W*Pi |
| 85 | K1/1.2 | 30.0 | 4 | TEX STO UUU UUU | 4MFP |
| 86 | K1/1.2/3 | 30.0 | 4 | TEX STO UUU UUU | 4MFP |
| 87 | K1/1.3/4* | 29.0 | 4 | TEX STO UUU UUU | 4MFPt |
| 88 | K1/1.3 | 29.0 | 4 | TEX STO UUU UUU | 4MFPt |
| 89 | K1/2.4 | 27.0 | 4 | STO UUU UUU UUU | 4MFPT |
| 90* | K1/3.4 | 34.0 | 4 | STO UUU UUU UUU | 5MFPT |
| 91 | K2.0/0.2 | 27.0 | 4 | TEX DRA UUU UUU | 4W*Pi |
| 92* | M3/2.2 | 47.0 | 2 | UUU UUU UUU UUU | 3Fwv |

| | | | | | |
|---|---|---|---|---|---|
| 93 | M3/3.2 | 47.0 | 2 | UUU UUU UUU UUU | 2fWv |
| 94 | M6-D3/2.2 | 48.0 | 2 | DRA UUU UUU UUU | 2Wf-4P*Wv |
| 95* | ML2/1.3 | 39.0 | 3 | TEX UUU UUU UUU | 5P*M*vt |
| 96* | N1/3.3 | 11.0 | 7 | DEP STO UUU UUU | 5R*Pt |
| 97 | N1.P- 4/2.4 | 2.0 | 7 | DEP STO UUU UUU | 7R*P*T-7R*T |
| 98 | NG1/3.2 | 50.0 | 2 | UUU UUU UUU UUU | 1w |
| 99 | NG1/3.1/2 | 49.0 | 2 | DRA UUU UUU UUU | 2w |
| 100 | NG1-G2/ | 45.0 | 2 | UUU UUU UUU UUU | not found |
| 101* | NG2/1.2 | 33.0 | 4 | TEX DRA UUU UUU | 2W |
| 102 | NG2/3.0 | 41.0 | 2 | DRA UUU UUU UUU | 2W |
| 103 | NG2/3.1 | 41.0 | 2 | DRA UUU UUU UUU | 2W |
| 104 | NG2/3.2 | 41.0 | 2 | DRA UUU UUU UUU | 2W |
| 105 | NG2/3/4.2 | 41.0 | 2 | DRA UUU UUU UUU | 2W |
| 106 | NG2-P4/ 3.1/2 | 41.0 | 2 | DRA UUU UUU UUU | 2W-2Wf |
| 107 | MG2.V-J5/ 2.2 | 50.0 | 2 | UUU UUU UUU UUU | 2W-4W*P |
| 108 | NG2/3/4.1 | 41.0 | 2 | DRA UUU UUU UUU | 2W |
| 109 | NG2-G3/3.1 | 41.0 | 2 | DRA UUU UUU UUU | 2W-3W*p |
| 110 | NG3/3.2 | 49.0 | 2 | UUU UUU UUU UUU | 2wv |
| 111 | NG3/3.3 | 47.0 | 2 | UUU UUU UUU UUU | 2wvt |
| 112 | NG3-M3/3.2 | 49.0 | 2 | UUU UUU UUU UUU | 2wv |
| 113 | O1.P/2.3 | 24.0 | 5 | STO UUU UUU UUU | 5P*MPt |
| 114 | O1.P/2.3/4 | 24.0 | 5 | STO UUU UUU UUU | 5P*MFt |
| 115 | O1.P/2.4 | 23.0 | 5 | STO UUU UUU UUU | 5P*MFt |
| 116 | O1.P-G1.P/ 2.4 | 22.0 | 5 | STO UUU UUU UUU | 5P*MFt-4P*T |

| | | | | | |
|---|---|---|---|---|---|
| 117 | O1-U1/1.3 | 28.0 | 4 | TEX STO UUU UUU | 4MFPt |
| 118 | P2/3.2 | 47.0 | 2 | UUU UUU UUU UUU | 2fwv |
| 119 | P3/3.2 | 50.0 | 2 | UUU UUU UUU UUU | 2W |
| 120 | P4/3.1 | 40.0 | 3 | DRA UUU UUU UUU | 2Wf |
| 121 | P4/3.1/2 | 40.0 | 3 | DRA UUU UUU UUU | 2Wf |
| 122 | P4/3.2 | 40.0 | 3 | DRA UUU UUU UUU | 2Wf |
| 123 | P4-J4/2.2 | 51.0 | 1 | DRA UUU UUU UUU | 2Wf-4W*(v)F |
| 124 | P4-U8/3/2.2 | 52.0 | 1 | DRA UUU UUU UUU | 2Wf-4F*Wv |
| 125* | P4-J5/2.2 | 51.0 | 1 | DRA UUU UUU UUU | 3Wf-4W*F |
| 126 | P4-G2/3.2 | 45.0 | 2 | DRA UUU UUU UUU | 2Wf-2pw |
| 127* | Q1.SP/2.3 | 1.0 | 7 | DEP STO UUU UUU | 4P*Rft |
| 128 | R2/3.3 | 44.0 | 2 | DRA UUU UUU UUU | 3DWt |
| 129 | R3/3.2 | 41.0 | 2 | DRA UUU UUU UUU | 2Wd |
| 130 | R3/4.1 | 46.0 | 2 | DRA UUU UUU UUU | 2Wd |
| 131 | R3/4.1/2 | 46.0 | 2 | DRA UUU UUU UUU | 2Wd |
| 132 | U1/1.2 | 36.0 | 3 | TEX UUU UUU UUU | 4F*M* |
| 133 | U1/1.3 | 35.0 | 4 | TEX UUU UUU UUU | 4F*M*t |
| 134 | U1/1.3* | 35.0 | 4 | TEX UUU UUU UUU | 4F*M*t |
| 135* | U1/1.4 | 34.0 | 4 | TEX UUU UUU UUU | 5MFT |
| 136* | U2/1.2 | 41.0 | 2 | TEX UUU UUU UUU | 4F*V |
| 137* | U2/2.2 | 56.0 | 1 | UUU UUU UUU UUU | 4F*V |
| 138* | U5/1.2 | 36.0 | 3 | TEX UUU UUU UUU | 5F*V |
| 139 | U7/1.2 | 36.0 | 3 | TEX UUU UUU UUU | 4F*Wv |
| 140 | U7/1.2* | 36.0 | 3 | TEX UUU UUU UUU | 4F*Wv |
| 141* | U13/1.2 | 39.0 | 3 | TEX DRA UUU UUU | 5W*F* |
| 142* | U13/1/2.2 | 39.0 | 3 | TEX DRA UUU UUU | 5W*F* |
| 143 | U13.P/1.2 | 23.0 | 5 | TEX DRA STO UUU | 5W*F*p |

| | | | | | |
|---|---|---|---|---|---|
| 144 | U14.0/0.1/2 | 14.0 | 5 | TEX DRA UUU UUU | SW*F*I |
| 145 | U14.0/0.1 | 14.0 | 5 | TEX DRA UUU UUU | SW*F*I |

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