Cluster analysis of barley breeding centers using environmental variables
by Thomas John Rice

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Soil Science
Montana State University
© Copyright by Thomas John Rice (1976)

Abstract:
Cluster analysis was used to group North American and world barley breeding centers by year-round environmental variables. North American centers were also grouped by growing season environmental variables.

Established groups were determined by a comparison of the initial groups formed by two different cluster analyses. Centers clustered in both analyses were designated as established groups.

Stepwise discriminant analysis generated an index of similarity between and within groups. Some single-member groups were assigned to established groups.

The cluster analyses using year-round variables grouped North American and world barley breeding centers that had similarities in soil classification. Soil and climatic characteristics were identified for each North American group through an examination of the soil classification names.

The cluster analyses by growing season variables grouped North American centers that had similar growing season environments. A factorial analysis of barley yields showed that centers within selected groups produced similar yields. Variety by center interactions did not exist in such instances.

Vanderbilt cluster analysis grouped Montana barley breeding centers in steps by growing season variables. A three dimensional model was developed which compares Montana centers environmentally.

Statement of Permission to Copy

In presenting this thesis in partial fulfillment of the require-
ments for an advanced degree at Montana State University, I agree that
the Library shall make it freely available for inspection. I further
agree that permission for extensive copying of this thesis for scholarly
purposes may be granted by my major professor, or, in his absence, by
the Director of Libraries. It is understood that any copying or
publication of this thesis for financial gain shall not be allowed
without my written permission.

Signature _____

Date_____ 5-27-76 _____

CLUSTER ANALYSIS OF BARLEY BREEDING

CENTERS USING ENVIRONMENTAL VARIABLES

by

THOMAS JOHN RICE

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science

Approved:

G.A. Nielsen
Chairperson, Graduate Committee

K C Feltner
Head, Major Department

Henry L. Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

May, 1976

iii

ACKNOWLEDGMENTS

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

vi

LIST OF TABLES

vii

LIST OF FIGURES

ABSTRACT

Cluster analysis was used to group North American and world barley breeding centers by year-round environmental variables. North American centers were also grouped by growing season environmental variables.

Established groups were determined by a comparison of the initial groups formed by two different cluster analyses. Centers clustered in both analyses were designated as established groups.

Stepwise discriminant analysis generated an index of similarity between and within groups. Some single-member groups were assigned to established groups.

The cluster analyses using year-round variables grouped North American and world barley breeding centers that had similarities in soil classification. Soil and climatic characteristics were identified for each North American group through an examination of the soil classification names.

The cluster analyses by growing season variables grouped North American centers that had similar growing season environments. A factorial analysis of barley yields showed that centers within selected groups produced similar yields. Variety by center interactions did not exist in such instances.

Vanderbilt cluster analysis grouped Montana barley breeding centers in steps by growing season variables. A three dimensional model was developed which compares Montana centers environmentally.

INTRODUCTION

Due to a multitude of land attributes and their interrelationships, it could be argued that every location on the earth's surface is environmentally unique. For classification purposes, environmental similarities among specific locations can be identified. Locations can subsequently be grouped using selected environmental variables.

The grouping of environmentally analogous barley breeding centers would facilitate the exchange of agricultural technology worldwide. Variety yield results, experimental results, and crop germplasm could be potentially exchanged among environmentally analogous centers.

Recognition of the similarities and differences among groups would result from a characterization of the common climatic and soil properties of centers within each group.

The purposes of this study were to:

1) collect environmental data from world barley breeding centers; 2) group environmentally analogous centers using two computerized cluster analysis programs and one computerized discriminant analysis program; 3) assemble soil classification information for each center; 4) characterize each group according to soil and climatic data derived from soil classification names; and 5) compare barley yield data among selected North American centers grouped by growing season variables.

REVIEW OF LITERATURE

Background

There is a widespread interest in international agricultural development and cooperation. The developing countries want to bypass many of the intermediate steps in the evolution of western agriculture, going as directly as possible from subsistence to modern farming (49). Although technology may not always be successfully transferred from one agricultural environment to another, the scientific principles on which sound agricultural practice is based are always transferable (15).

In an introduction to a study of barley-climate relationships, Nuttonson (29) stated that some of the major barley producing regions of the Western and Eastern Hemispheres, though geographically far apart, are often rather similar in their main characteristics of relief, climate, and soils. His study, however, did not include information on the relief or soils of barley regions, but centered on an analysis of barley testing sites that were similar according to the number of degree-days required for barley to mature (29). Nuttonson (29) believed that a great amount of crop performance data accumulated in the several decades prior to 1957 suggested that year-to-year variations in barley growth and development were due mostly to climate.

Gardiner (14) showed that climate was an important crop ecological factor particularly for crops such as sugar beets whose

varietal constant is higher than that obtainable in Ireland. He discussed the desirability of producing crops under the most suitable soil and climatic conditions.

McGuire and McNeal (25) showed that quality characteristics of hard red spring wheat cultivars do not respond similarly when the environment favoring these quality traits improves. They stated that cultivar X environment interactions known to exist can be properly assessed only when several location tests are used.

In 1975, Wortman (49) stated that the International Board for Plant Genetic Resources is concerned with the systematic collection, evaluation, preservation, and exchange of germplasm of the basic food crops. He explained the need for adequate crop protection when germplasm is exchanged. Momitoring the spread of important organisms, such as the rusts of wheat, blast of rice, and vectors of virus diseases, is important when germplasm exchange is undertaken. Without safeguards against disease, the potential benefits could be quickly destroyed. Locations that have similar climates may have similar disease problems.

In its 1974 Review (1), CIMMYT (International Maize and Wheat Improvement Center) expressed a desire to learn more about the climatic circumstances under which maize and wheat are grown. They asked such questions as what climatic factors are critical in each of the world's maize and wheat areas, and where and what diseases and

insects are most threatening. CIMMYT believed that these questions were relevant as priorities were established for crop research.

A University of Hawaii research team is currently collecting and examining soil classification information from agricultural research stations through the Semi-Arid Tropics as part of a project funded by A.I.D. (Agency for International Development). Their hypothesis is that stations with the same soil classification name at the family level in Soil Taxonomy may exchange agricultural technology.

A project funded by A.I.D. is currently in progress at Montana State University that has as its main objective the development of barley strains which are readily adaptable to developing semi-arid countries where soils are generally poor and drought is commonplace. This research effort has proved to require expertise from several disciplines.

The desire to exchange agricultural technology from one location to another is expressed in the literature. Recognition of crop-climate-soil interrelationships will facilitate technology exchange. Technology will be most successfully transferred among locations grouped according to similar environment.

Classification

Grouping barley breeding centers according to similar environment presented a problem of classification.

Classification is an important aspect of most sciences, and similar principles and procedures have been developed independently in various fields (34). All classifications aim to achieve economy of memory through an arrangement and organization of facts about the diversity of things (7).

Sokal (34) defined classification as the ordering or arrangement of objects into groups or sets on the basis of their relationships. In a more philosophical vein, Whitehead (46) defined classification as a halfway house between the immediate concreteness of the individual thing and the complete abstraction of mathematical notions.

The paramount purpose of a classification is to describe the structure and relationship of the constituent objects to each other and to similar objects, and to simplify these relationships in such a way that general statements can be made about the classes of objects (34).

Adansonian principles of classification (6) were used to group the barley breeding centers in this study. These principles are: 1) ideal natural taxonomy is one in which the taxa have the greatest content of information; 2) every natural feature is of equal weight when constructing a classification; 3) affinity is a function of proportion of features in common; and 4) affinity is independent of phylogeny (evolution of the species).

Classifications that yield similarities or dissimilarities between all objects taken a pair at a time can be determined by cluster analysis (34). A symmetric matrix of similarity or dissimilarity coefficients can be analyzed by a computer to represent their relationships as clusters (34).

Properties of clusters include their location in space (some measure of central tendency), their dispersion, their shapes, their connectivity (a measure of how many pairs of operational taxonomic units within a cluster are more similar to each other than a certain arbitrary criterion), and the magnitude of the gaps between clusters (34).

Cluster analysis was chosen as a tool to group barley breeding centers by environmental variables.

Barley Distribution

Barley is successfully cultivated in a wider range of climate than any other cereal (29). The wide ecological range and the diverse adaptabilities of the many varietal types of barley are evidenced by the fact that barley cultivation is widely distributed from north to south and from areas below sea level to high mountain ranges. Likewise, barley breeding centers follow this pattern.

In the north, barley breeding in Europe extends near the Arctic Circle at Hameenlinna, Finland (61° 08' N latitude) and barley cultivation reaches 70° N latitude in Norway. In North America,

barley is grown as far north as about 64° N latitude in the Tanana
Valley in Alaska and is bred at Palmer, Alaska (61° 34' N latitude).

In the lower latitudes of Africa and Asia, barley varieties are
developed in the plains of India (Samastipur, 26° 59' N latitude),
in the lower Delta of the Nile (Cairo, A.R. of Egypt, 30° 02' N
latitude), and in the high mountain regions of Kenya (Njoro, 0° 20' S
latitude, 2164 m. elevation), where barley breeding extends closest
to the equator.

The distribution of barley cultivation in North America was
studied in detail by Weaver (45). He has found that from Western
Iowa eastward to the Atlantic seaboard, the isotherm, indicating an
average summer temperature (June through August) of 70°F (21.1°C),
parallels with remarkable precision the general location of the
southern limit of the dependable growth of spring barley.

Regardless of temperature, spring barley is not grown on an
important scale in North America where the annual precipitation is
greater than 35 inches (889 mm) (45).

An important pivotal point in the climatic relations of barley
is found in northwest Iowa where the lines indicating an average
summer temperature equal to 70°F (21.1°C), an average annual
precipitation equal to 30 inches (762 mm) and an average relative
humidity for July equal to 55% intersect (45). South and east of
these lines, spring barley production appears limited.

The extensive production of winter barley is not successful where average winter temperatures are much below the freezing point. The Corn Belt Region, situated largely between the $30^{\circ}F$ ($-1.1^{\circ}C$) winter isotherm on the south, and the $70^{\circ}F$ ($21.1^{\circ}C$) isotherm on the north, is climatically unsuited to the growing of either winter or spring barley (45). Just as the $70^{\circ}F$ ($21.1^{\circ}C$) isotherm seems to be associated with an important climatic barrier for spring barleys, it appears to be critical in the delimitation of the southern margin of winter barley cultivation as well.

Barley is not a single cultivated plant today, but a polymorphous race of different plants, each with a long and complex history. Each variety is adapted to different ecological conditions, serving a unique function and taking a particular place in agriculture. Nevertheless, there exist some basic similarities in the barley-climate-soil relationships among varieties.

The following sections will serve to point out some basic similarities important in barley-climate-soil interrelationships. Through identification of the environmental factors important to barley growth, variables were chosen by which barley breeding centers were grouped.

Barley-Soil Relationships

In regions with strongly unfavorable temperature and rainfall conditions, the edaphic features of an environment are unable to

override climatic influences to the extent that permanently stable areas of barley cultivation may be established. However, the occurrence of excellent barley soils does stimulate temporary and local extensions of barley into some climatically unfavorable situations (45).

The edaphic conditions for optimum barley growth include the following major features:

1) The soils should be well-drained (21). For this reason, heavy clays (21) and peaty soils are generally unsuitable for barley production. Sandy soils are also poor for barley production (47). The best textures are the loams and silt loams.

2) The high fertility requirements of barley necessitate the presence of adequate supplies of moisture and readily accessible mineral nutrients in the surface layers of the soil. It has been noted that barley is more sensitive to nutrient deficiencies than wheat (17). The rate of decline of barley at Rothamsted Experimental Farm, England during 40 years of continuous cropping without fertilization was considerably greater than that of wheat (17).

3) Barley, in general, will not tolerate acid soils, although it will successfully withstand moderate concentrations of sodium (24). The maximum yields are obtained from soils

with a pH neutral to slightly alkaline (i.e. pH 7 to 8).
Nevertheless, in studies conducted to determine aluminum
tolerance in barley varieties (12, 13), it was found that
barley varieties differ in their tolerance to aluminum.
Some varieties survived well at pH's as low as 4.5.

4) Barley is the most salt tolerant of the cereals. In
studies by the United States Salinity Laboratory (40), it
was determined that an electrical conductivity of a
saturation extract of 16 mmhos/cm will cause a 50% reduction
in the yield of barley grain. Since barley is more tolerant
of high levels of salinity than other commonly grown crops,
it is recommended on land that is being reclaimed by
leaching and levelling.

The Chernozem soils (Haploboroll, Argiboroll, Argiustoll,
Haplustoll) represent the ideal soils for barley production (45).
While the typically moderate rainfall of the Chernozem region does
not lead to a detrimental leaching of the soil, it normally does
provide a sufficient amount of moisture to mature crops with maximum
yields.

The fact that the highest barley yields in North America are
commonly obtained under irrigation in the Western States is partially
explained by the inherent suitability of unleached dryland soils for
barley, when the hazard of drought is eliminated (45).

Although the best barley soils in Wisconsin are inferior in their natural state to the Chernozem soils farther west, the average barley yields in the eastern part of this state have, with the exception of a few irrigated areas in the West, been higher than any other section of the country (45). Certainly farm management and prevailing cultural techniques have had a large influence in creating this situation.

Satisfactory barley production in the Pedalfer zone is almost entirely restricted to soil types belonging to two large groups (45):

1) Prairie soils: Argiudoll, Haplustalf, Argiustoll.

2) Gray-brown Podzolic soils: Hapludalf.

A list of barley soils of particular importance to barley production in North America was prepared (45). The classification of these soil series was obtained from the Soil Conservation Service (33). Comparison of this list of soil series with soil classification information returned from barley breeders showed many of these soils present at North American barley breeding centers. The soil series and their soil classification follows.

Series (State)	Soil Classification
1) Barnes (North Dakota)	Udic Haploboroll, fine-loamy, mixed
2) Bearden (North Dakota)	Aeric Calciaquoll, fine-silty, frigid
3) Fargo (North Dakota)	Vertic Haplaquoll, fine, montmorillonitic, frigid
4) Moody (South Dakota)	Udic Haplustoll, fine-silty, mixed, mesic
5) Tama (Iowa)	Typic Argiudoll, fine-silty, mixed, mesic
6) Clinton (Iowa)	Typic Hapludalf, fine, montmorillonitic, mesic
7) Kewaunee (Wisconsin)	Typic Hapludalf, fine, mixed, mesic
8) Miami (Wisconsin)	Typic Hapludalf, fine-loamy, mixed, mesic
9) Clarion (Iowa)	Typic Hapludoll, fine-loamy, mixed, mesic
10) Keith (Nebraska)	Aridic Argiustoll, fine-silty, mixed, mesic
11) Weld (Colorado)	Aridic Paleustoll, fine, montmorillonitic, mesic
12) Bridgeport (Kansas)	Fluventic Haplustoll, fine-silty, mixed, mesic
13) Tripp (Nebraska)	Aridic Haplustoll, coarse-silty, mixed, mesic
14) Yolo (California)	Typic Xerochrept, fine-silty, mixed, thermic
15) Capay (California)	Typic Chromoxerert, fine, montmorillonitic, thermic

Soil-Climate Relationships

Barley breeding centers are characterized by microclimates that may differ considerably from the macroclimate of a region. Nevertheless, general climatically-determined soil properties can be compared among centers on a worldwide, continental, or statewide scale.

The role of climate in soil formation is exemplified best on a worldwide basis (6). The climatic factor is considered to be the most important factor determining the properties of many soils (18).

Soil taxonomy in the United States today uses mean annual soil temperature and moisture regimes as soil properties that can be used to define taxa (31). Moisture and temperature are the two aspects of climate paramount in controlling soil properties (5). Moisture is important because water is involved in most of the physical, chemical, and biochemical processes that go on in a soil. Also, the amount of moisture delivered to the soil surface influences the weathering and leaching conditions with depth in the soil. Temperature influences the rate of chemical and biochemical processes (5).

The main soil morphological and mineralogical properties that correlate with climate are organic matter content, clay content, kind of clay minerals, color, the presence or absence of $CaCO_3$, and depth to the top of the $CaCO_3$-bearing horizon (5).

Barley-Climate Relationships

The USDA Yearbook of Agriculture, 1936, states that barley does not grow well in hot, humid climates. Under arid conditions, barley culture is successful even in the tropics, but under humid conditions, it grows well only in cooler regions. The inability of barley to withstand the simultaneous occurrence of high temperature and high humidity and still maintain a consistent level of high quality production is of importance in the delimitation of major regions of barley cultivation in North America (45).

Barley matures in a shorter length of growing season than other small grains. Due to this ability to mature in a short period, barley can be described as a drought-escaping rather than a drought resistant crop (29).

Spring barley varieties have different lengths of growing season. In addition to inherent varietal differences, this variation is a result of local influences of temperature, daylength, solar radiation, and soil moisture.

Spring barley phenology A more detailed look at the phenology of spring barley will serve to point out some important relations. Three stages of growth will be examined.

Stage 1. Sowing to emergence - The average requirement for emergence is 5 to 7 days depending on soil moisture and soil temperature conditions (29). Barley seed begins to germinate at 35°F

(1.7°C), but at such temperatures emergence is slow. Biological activity becomes significant as the soil temperature rises to about 39°F (4°C) with the optimum temperature for emergence being in the range of 59° to 68°F (15° to 20°C) (16).

Dry soil can delay emergence. Also, cold, wet soil is detrimental due to attacks of fungus disease or to restricted supply of oxygen (29).

Stage 2. Seedling emergence to spike emergence - During this development phase, all the leaves are produced, and the two yield factors, grain per spike and spikes per plant, are largely determined (16).

It is well known that photoperiod is strongly linked with development at this stage, with long photoperiods encouraging a more rapid change from vegetation to reproductive growth (16).

After the first three or four leaves have been produced, the plants begin to tiller. The period from emergence to the start of tillering averages 10 to 15 days, but may be as long as 20 to 25 days (29). The production of the first 4 tiller buds is independent of environment and is related to internal plant factors (19). A large number of tillers are produced, but only a small fraction survive to bear spikes. Conditions which have been found to favor tiller production survival include heavy nitrogen fertilization and illumination of the growing tillers (19, 20).

The period when flowers are beginning to form (stamen initiation) is particularly sensitive to the quantity of incident radiation (2). Long photoperiods reduce the total number of fertile spikelets (16).

Moisture stress prior to stamen initiation reduces the final spikelet number and high ambient temperature (20°C compared to 15°C) can reduce head size (37).

The period from shooting to shortly after heading, often called the boot stage, is a period during which barley is most sensitive to temperature and soil moisture conditions (29). During this time, insufficient water and temperature extremes may adversely affect pollination (16).

Stage 3. Spike emergence to dead ripeness - Controlled experiments by Thorne et al. (37) showed that cool conditions considerably extended the ripening period, but the effect was reduced if conditions were also cool before anthesis. In the same experiment, short days after anthesis increased the ripening time. Temperature seems to be of primary importance, however (37).

Winter barley phenology Somewhat different conditions exist for winter barley. Sowing date, and its indirect influence on tillering, is a dominant factor. A timely and well-prepared seedbed, sufficient soil moisture and plant nutrients, and optimum temperatures are other important factors for adequate fall tillering of winter barley (29).

When seedlings emerge at temperatures of 59° to $69^{\circ}F$ (15° to $20.6^{\circ}C$) with normal sowing, tillering begins at about 56° to $58^{\circ}F$ (13.3° to $14.4^{\circ}C$), and ceases when temperatures drop to 36° to $37^{\circ}F$ (2.2° to $2.8^{\circ}C$) (29). When sowing is late, the seedlings may emerge at temperatures of $43^{\circ}F$ ($6.1^{\circ}C$) or lower and there is no time left for the formation of the tillering node before winter (29). Thus, the plants do not tiller or become well-rooted in the fall.

Even with adequate fall tillering, winter barley normally starts additional tillering with the beginning of warm temperatures in the spring (29). If it is too dry in the spring, winter barley tillers, but weakly, as it does under dry fall conditions.

Winter barley which had developed weakly in the fall passes quickly to the boot stage during a warm spring, without having time to compensate for insufficient fall tillering (29).

Too early sowing may, likewise, be detrimental (29). It may cause the barley to joint in fall, and may be conducive to depletion of soil moisture in areas of limited precipitation. Early sowing may result in excessive growth and vegetative development during the fall, which leads to a loss of winter hardiness (29).

Temperature, precipitation, and solar radiation are cited as primary climatic determinants of optimum barley growth. These variables were used to characterize each barley breeding center.

MATERIALS AND METHODS

Composite Overlay Map

The map in Figure 1 is a composite of overlay maps used to repre-
sent dryland barley production constraints imposed by: 1) soil, 2)
precipitation, 3) evapotranspiration, and 4) growing season (28).
Areas that appear darkest have the greatest limitation for production
of dryland barley. Clear areas or "windows" are areas where dryland
barley is expected to thrive and where, in fact, most barley breeding
centers (black dots in Figure 1) are located.

Data Collection

A mailing list was prepared from the addresses of subscribers to
the Barley Genetics Newsletter. A questionnaire, three pages in
length (See Appendix 1), was sent to selected world barley breeders
and geneticists. The questionnaire asked for information about
location of the barley breeding center, average barley planting and
harvest dates, mean monthly precipitation, mean monthly maximum and
minimum temperatures, soil texture, soil classification name,
physiography of the center, and general agricultural management.
Detailed data from the questionnaires are on file in the Plant and
Soil Science Department.

Precipitation and temperature data received from the centers
were cross-checked using climatic summaries (26, 36, 39, 48).

Mean monthly global radiation data were collected from figures
and world maps contained in "World Distribution of Solar Radiation" (23).

vertisols
oxisols
ultisols
frost free season <
precip.<100mm
precip. 100-250
precip. >1000m
daily evapotranspiration
>.35 (max)

Figure 1:   COMPOSITE OVERLAY MAP SHOWING ENVIRONMENTAL
CONSTRAINTS TO DRYLAND BARLEY PRODUCTION

Saturation vapor pressure figures were derived from tables by Papadakis (30).

Potential evapotranspiration data were derived from the solar-thermal unit concept devised by Caprio (8). A computer program supplied by Dr. J. M. Caprio using the solar-thermal unit concept gave the potential evapotranspiration figures used in this study.

Daylength data were expressed as the mean possible duration of sunlight each month in units of 30 days of 12 hours each (38).

Soil classification data were received in questionnaires returned from world barley breeders. References from the United States (32, 33), Canada (27), Europe (22), Australia (35), and the world (10, 11) were used to obtain soil correlation information.

Statistical Computer Programs

Three computerized statistical programs adapted to the Xerox Sigma 7 computer in Montana State University's Computing Center analyzed the data.

The computer programs used and a brief description of each follows:

1) Vanderbilt Cluster Analysis-Hierarchical Grouping (44); "The goal of this program is to form a group such that the sum of the squared within-group deviations about the group mean of each profile variable is minimized for all profile variables in all groups at the same time" (44).

2) BMDP2M-Cluster Analysis of Cases (3); "This program clusters cases according to a measure of distance. The two cases having the shortest distance between them are amalgamated and treated as one case and then, in turn, clustered with others. This algorithm continues until all cases and clusters are amalgamated into one cluster.

This distance between cases is either the pth root of the sums or the pth power of differences or chi-square or X^2/n computed from the table formed by the two cases and the variables" (3). Mathematical equations describing the distance are contained in the reference (3).

Groups were established by comparing the initial groups formed by these two cluster analyses. Not all centers were assigned to a group. These centers were called single-member groups. With the use of the following analysis, some single-member groups were assigned to established groups.

3) BMD07M-Stepwise Discriminant Analysis (4); "This program performs a multiple group discriminant analysis. A set of linear classification functions is computed by choosing the independent variables in a stepwise manner. The variable entered at each step is selected by one of four available criteria, and a variable is deleted when its F-value becomes too low. Using these functions and prior probabilities, the posterior probabilities of each case belonging to each group is computed" (4). A posterior probability

of one was used to assign some single-member groups to established groups.

North American Centers Grouped By Year-Round Variables

North American barley breeding centers were grouped with the use of two computerized cluster analyses (3, 44) and one stepwise discriminant analysis (4). The 53 environmental variables used were:

Latitude--1;

Elevation--1,

Growing Season--3,

Mean Monthly Precipitation--12,

Mean Monthly Maximum Temperature--12,

Mean Monthly Minimum Temperature--12, and

Mean Monthly Global Radiation--12.

After groups were established, soil classification information for each center was listed. Soil and climatic characteristics common to each North American group were collected with the use of soil classification information and Soil Taxonomy (32).

World Centers Grouped By Year-Round Variables

World barley breeding centers were grouped with the use of two computerized cluster analyses (3, 44). The 53 environmental variables used were:

Latitude--1,

Elevation--1,

Growing season--3,

Mean Monthly Precipitation--12,

Mean Monthly Maximum Temperature--12,

Mean Monthly Minimum Temperature--12, and

Mean Monthly Global Radiation--12.

Data for Southern Hemisphere centers were arranged July through June to correspond with January through December at Northern Hemisphere centers. After the groups were established, soil classification information for the centers, when available, was listed. Foreign soil classification names were correlated with Soil Taxonomy (32) using world (10, 11), Canadian (27), and Australian (35) references.

North American Centers Grouped By Growing Season Variables

North American centers were also grouped according to growing season variables. The two cluster analyses (3, 44) and one discriminant analysis (4) were used.

The 35 environmental variables used were:

Elevation--1,

Percent sand, silt, and clay--3,

Physiography--1,

Precipitation during the growing season--1,

Precipitation outside the growing season--1,

Maximum temperature*--4,

Minimum temperature*--4,

Global radiation*--4,

Daylength*--4,

Potential evapotranspiration*--4,

Saturation vapor pressure*--4, and

Cumulative solar-thermal units*--4.

Precipitation during and outside the growing season was computed from precipitation data using average planting and harvest dates reported in the questionnaire.

The average length of barley growing season was computed from barley planting and harvest dates. Growing season lengths were divided by three to obtain increments representing one third of the growing season. Dates representing the end of the first third and end of the second third of the growing season were computed using these increments (See Table 6).

A graph for each North American center was prepared on which mean monthly maximum and mean monthly minimum temperatures were plotted. Temperature data for the growing season were extrapolated from these graphs. Graphs of the type shown in Figure 2 were prepared for all North American centers.

---

* Data were derived to correspond with growing season dates at planting, end first third, end second third, and harvest.

Bozeman, Montana

	Planting	$^1/_3$	$^2/_3$	Harvest
Maximum Temperature	16.5°C	21.5°C	27.5°C	26.0°C
Minimum Temperature	1.0°C	6.5°C	8.5°C	7.0°C

FIGURE 2: EXAMPLE OF GRAPH FROM WHICH GROWING SEASON AIR
TEMPERATURES FOR NORTH AMERICAN CENTERS WERE
DETERMINED.

Global radiation, potential evapotranspiration, and solar-thermal unit data were derived from output obtained from a computer program supplied by Dr. J. M. Caprio.

Daylength data were derived using the figures from Thornthwaite (38).

Saturation vapor pressure data were derived using the figures computed from Papadakis (30).

Yield data for selected barley varieties were compiled from annual reports of uniform barley nurseries in Canada (41, 43), and the United States (42).

Factorial analysis was applied to test differences within and between North American groups.

Yield data from the Western Cooperative Barley Nursery in Canada were used in the analysis since that nursery included 5 centers from 2 established groups (i.e. Brandon and Winnipeg; Group 6, and Edmonton, Beaverlodge, and Saskatoon; Group 8).

Montana Centers Grouped By Growing Season Variables

Montana centers were grouped using the Vanderbilt cluster analysis (44). The 62 environmental variables used were:

Elevation--1,

Latitude--1,

Percent sand, silt, and clay--3,

Physiography--1,

Average barley planting and harvest dates and total length of

the growing season--3,

Mean monthly precipitation (April through August)--5,

Mean monthly maximum temperature (April through August)--5,

Mean monthly minimum temperature (April through August)--5,

Mean monthly global radiation (April through August)--5,

Soil classification name--30,

Maximum and average soil pH--2, and

Total potential evapotranspiration during the growing season--1.

The centers were grouped in a stepwise manner by the cluster

analysis. At each step, the groups were compared with a 3-dimensional

model (See Figure 4) prepared by assigning a value between 0 and 100

to the environmental data for each center. The lowest value was

assigned 0 and the highest value 100. For example, Huntley had the

lowest moisture index (i.e. 0) and Moccasin had the highest moisture

index (i.e. 100). All other centers had intermediate moisture index

values.

RESULTS

Results of Cluster Analysis

North American centers grouped by year-round variables Table 1

contains a list of 38 North American centers grouped by 53 year-round

variables. Eight groups were established after an examination of the

three analyses.

An asterisk next to a center indicates that it was added to a

group only after the final stepwise discriminant analysis (4). These

centers were not as representative of the group as those centers

assigned by the cluster analyses (3, 44).

Even after the final discriminant analysis (4), 5 centers were

not assigned to groups. These centers were called single-member groups

and can be described as environmentally unique among North American

centers.

Table 2 contains the common soil and climatic characteristics

collected for North American groups using soil classification names

and Soil Taxonomy (32).

World centers grouped by year-round variables Table 3 contains a

list of 110 world centers grouped by 53 year-round variables. Twenty-

five groups were established. Thirteen centers were not assigned to

groups. These centers were called single-member groups and could be

described as environmentally unique among world centers.

North American centers grouped by growing season variables   Table
4 contains a list of 38 North American centers grouped by 35 growing
season variables.   Among the 38 centers, 4 centers grew both winter
and spring barley.   Therefore, there were 2 sets of data (winter and
spring) for these 4 centers making 42 locations that were grouped in
the analyses.

An asterisk next to a center indicates that it was added to a
group only after the final stepwise discriminant analysis (4).   These
centers are not as representative of the group as those centers assigned
by the two cluster analyses (3, 44).

Twelve groups were established for North American centers.   Eight
centers were not assigned to a group.   These have unique growing season
environments among North American centers.

Montana centers grouped by growing season variables   Table 5
contains the steps by which 6 Montana centers were grouped by 62
growing season variables in the Vanderbilt cluster analysis (44).
Centers with fewer similarities were grouped in succeeding steps by
this analysis.

TABLE 1: SOIL CLASSIFICATION OF NORTH AMERICAN CENTERS GROUPED BY YEAR-ROUND VARIABLES.

| GROUP NUMBER | SOIL CLASSIFICATION | |
AND LOCATION	SUBGROUP	FAMILY**

GROUP 1
BOZEMAN, MONTANA. . . . . TYPIC CRYOBOROLL, FINE-SILTY, MIXED
*HAVRE, MONTANA. . . . . .ARIDIC ARGIBOROLL, FINE-LOAMY, MIXED
*KALISPELL, MONTANA. . . . . UDIC HAPLOBOROLL, COARSE-SILTY, MIXED
                                            TYPIC EUTROCHREPT, FINE-SILTY, MIXED, FRIGID
LETHBRIDGE, ALBERTA . . . . TYPIC BOROLLS (DARK BROWN CHERNOZEM)
MOCCASIN, MONTANA . . . . TYPIC ARGIBOROLL, FINE, MONTMORILLONITIC
                                            TYPIC CALCIBOROLL, FINE-LOAMY, CARBONATIC

GROUP 2
BROOKINGS, SOUTH DAKOTA . . . . UDIC HAPLOBOROLL, FINE-LOAMY, MIXED
FARGO, NORTH DAKOTA . . . . .VERTIC HAPLAQUOLL, FINE, MONTMORILLONITIC, FRIGID
SIDNEY, MONTANA . . . . TYPIC ARGIBOROLL, FINE-SILTY, MIXED

GROUP 3
BRANDON, MANITOBA . . . . CALCIBOROLL (BLACK CHERNOZEM)
*LARAMIE, WYOMING. . . . . ARGIC CRYOBOROLL, FINE-LOAMY OVER SAND OR
                                            SANDY-SKELETAL, MIXED
SASKATOON, SASKATCHEWAN . . . . TYPIC BOROLLS (CHERNOZEMIC DARK BROWN)
WINNIPEG, MANITOBA. . . . . .UDIC HAPLOBOROLL (GLEYED REGO BLACK)

GROUP 4
GUELPH, ONTARIO . . . .(MOLLIC) EUTROCHREPT (MELANIC BRUNISOL)
MACDONALD COLLEGE, QUEBEC . . . . CHATEAUQUAY SERIES (CANADA)
OTTAWA, ONTARIO . . . . . . TYPIC AQUOLL OR TYPIC HUMAQUEPT (REGO HUMIC GLEYSOL)
*ST. PAUL, MINNESOTA . . . . AQUIC FRAGIOCHREPT, COARSE-LOAMY, MIXED, FRIGID
                          TYPIC (GLOSSIC) EUTROBORALF, FINE, MIXED
                                            TYPIC FRAGIOCHREPT, COARSE-LOAMY, MIXED, FRIGID
                                            DYSTRIC EUTROCHREPT, COARSE-LOAMY, MIXED, FRIGID

GROUP 5
*ABERDEEN, IDAHO . . . . XEROLLIC CALCIORTHID, COARSE-LOAMY, MIXED, MESIC
*CORVALLIS, OREGON . . . . .AQUULTIC ARGIXEROLL, FINE-SILTY, MIXED, MESIC
FORT COLLINS, COLORADO. . . . . .ARIDIC ARGIUSTOLL, FINE, MONTMORILLONITIC, MESIC
LOGAN, UTAH . . . . .TYPIC HAPLOXEROLL, COARSE-SILTY, CARBONATIC, MESIC
PENDLETON, OREGON . . . . .TYPIC HAPLOXEROLL, COARSE-SILTY, MIXED, MESIC
PULLMAN, WASHINGTON . . . . PACHIC ULTIC HAPLOXEROLL, FINE-SILTY, MIXED, MESIC

GROUP 6
BEAVERLODGE, ALBERTA. . . . . GLOSSIC NATRIBORALF (DARK GRAY SOLOD)
EDMONTON, ALBERTA . . . . ALBIC (UDIC) ARGIBOROLL (ELUVIATED BLACK CHERNOZEM)
*PALMER, ALASKA. . . . . TYPIC CRYORTHENT, COARSE-SILTY OVER SAND OR
                                            SANDY-SKELETAL, MIXED, NONACID

GROUP 7
ATHENS, GEORGIA . . . . .TYPIC HAPLUDULT, COARSE-LOAMY, MIXED, THERMIC
WARSAW, VIRGINIA. . . . . .TYPIC HAPLUDULT, FINE-LOAMY, SILICEOUS, MESIC

GROUP 8
COLUMBIA, MISSOURI. . . . . UDOLLIC OCHRAQUALF, FINE, MONTMORILLONITIC, MESIC
ITHACA, NEW YORK. . . . . AERIC OCHRAQUALF, FINE-SILTY, MIXED, MESIC
LAFAYETTE, INDIANA. . . . . TYPIC ARGIAQUOLL, FINE-LOAMY, MIXED, MESIC
*AMES, IOWA. . . . . .AQUIC HAPLUDOLL, FINE-LOAMY, MIXED, MESIC
                                            TYPIC HAPLAQUOLL, FINE-LOAMY, MIXED, MESIC
                                            TYPIC ALBAQUALF, FINE, MONTMORILLONITIC, MESIC
*LINCOLN, NEBRASKA . . . . .TYPIC ARGIUDOLL, FINE, MONTMORILLONITIC, MESIC
*MADISON, WISCONSIN. . . . . .TYPIC HAPLUDALF, FINE-LOAMY, MIXED, MESIC

SINGLE-MEMBER GROUPS
A. MESA, ARIZONA. . . . . .TYPIC CALCIORTHID, COARSE-LOAMY, MIXED, HYPERTHERMIC

B. DAVIS, CALIFORNIA. . . . . TYPIC XEROCHREPT, FINE-SILTY, MIXED, THERMIC

C. HUNTLEY, MONTANA . . . . .USTOLLIC HAPLARGID, FINE-LOAMY, MIXED, MESIC
                                            USTIC TORRIFLUVENT, FINE, MONTMORILLONITIC,
                                            CALCAREOUS, MESIC

D. STILLWATER, OKLAHOMA . . . . UDERTIC PALEUSTOLL, FINE, MIXED, THERMIC

E. DENTON, TEXAS. . . . . .UDIC PELLUSTERT, FINE, MONTMORILLONITIC, THERMIC
                                            TYPIC USTOCHREPT, LOAMY, CARBONATIC, THERMIC,
                                            SHALLOW
                          VERTIC CALCIUSTOLL, FINE, MONTMORILLONITIC, THERMIC
                          LITHIC CALCIUSTOLL, CLAYEY, MONTMORILLONITIC, THERMIC

* Added to group after stepwise discriminant analysis.
** Canadian soil classification names in parentheses.

TABLE 2: SOIL AND CLIMATIC CHARACTERISTICS COMMON TO EACH NORTH AMERICAN GROUP.

GROUP	MEAN ANNUAL SOIL TEMPERATURE	SOIL MOISTURE REGIME	OTHER SOIL PROPERTIES
1	$< 8^oC$ (47^oF) (Frigid)	Ranges from moist to very dry (Udic to Aridic).	a. Freely-drained b. Base saturation $>$ 50% in surface horizon. c. Organic matter $>$ 1% in upper 18 cm. d. Soil structure is granular, crumb, or blocky in surface horizon. e. Dark color in surface horizon.
2	Same as Group 1.	Dry $<$ 90 days, cumulative. Soil are moist most, if not all, of the year (Udic, Aquic).	Same as Group 1.
3	Same as Group 1.	One center is moist (Udic), but there is no moisture regime included from other centers.	Same as Group 1.
4	Same as Group 1.	Same as Group 2.	a. Freely-drained. b. Surface horizon is generally light-colored and low in organic matter. c. Most soils have an altered subsurface horizon.
5	8° to 15^oC (47^c to 59^oF) (Mesic)	Ranges from dry and very dry (Ustic to Aridic) to warm and dry in summer and cool and moist in winter (Xeric).	a. Base saturation $>$ 50% in surface horizon. b. Organic matter $>$ 1% in upper 18cm except in drier soils (Aridisols). c. Carbonates have accumulated in subsurface horizons.
6	$< 8^oC$ (47^oF). Mean annual summer soil temperature $<15^oC$ (59^oF) at a 50 cm depth, if there is no organic surface horizon (Cryic)	Dry $<$ 90 days, cumulative, and moist most of the year (Udic).	Soil properties vary widely among centers.

31

TABLE 2: CONTINUED.

GROUP	MEAN ANNUAL SOIL TEMPERATURE	SOIL MOISTURE REGIME	OTHER SOIL PROPERTIES
7	Ranges between 8° to 15^OC (47° to 59^OF) (Mesic) and 15° to 22^OC (59° to 72^OF) (Thermic).	Dry $<$ 90 days, cumulative, and moist most of the year (Udic).	a. Freely-drained. b. Base saturation $<$ 50% in surface horizon. c. Light-colored surface horizon that is low in organic matter. d. Clay has accumulated in subsurface horizons.
8	Same as Group 5.	Ranges from moist to wet (Udic to Aquic).	a. Mottling occurs somewhere in the profile at most centers. b. Clay has accumulated in subsurface horizons.
Single-Member Groups Mesa, Arizona	$>22^OC$ (72^OF) (Hyperthermic)	Dry in some parts as long as 90 consecutive days in a growing season and dry in all parts more than half of the growing season (Aridic).	a. Surface horizon is generally light-colored and low in organic matter. b. Soils are calcareous in all parts above a zone of carbonate accumulation. c. Carbonates have accumulated in subsurface horizons.
Davis, California	15° to 22^OC (59° to 72^OF) (Thermic)	Warm and dry in summer and cool and moist in winter (Xeric).	a. Light-colored surface horizon. b. Accumulation of carbonates in a subsurface horizon or base saturation $>$ 60% in some sub-surface horizon. c. Altered subsurface horizon.
Huntley, Montana	Same as Group 5.	Dry in some part $>$ 90 days, cumulative, but is dry less than half the growing season in all parts (Ustic).	a. Surface horizon is generally light-colored and low in organic matter. b. Clay has accumulated in sub-surface horizons.

32

TABLE 2:   CONTINUED.

GROUP	MEAN ANNUAL SOIL TEMPERATURE	SOIL MOISTURE REGIME	OTHER SOIL PROPERTIES
			a. Base saturation > 50% in surface horizon.
			b. Organic matter > 1% in upper 18 cm.
Stillwater, Oklahoma	Same as Davis.	Same as Huntley.	c. Dark color in surface horizon.
			d. Clays accumulate in a thick, red subsurface horizon.
			e. Soils have deep, wide cracks in most years.
Denton, Texas	Same as Davis.	Same as Huntley.	Wide range of soils occurs at center.

TABLE 3: SOIL CLASSIFICATION OF WORLD CENTERS GROUPED BY YEAR-ROUND VARIABLES.

GROUP NUMBER AND LOCATION	SOIL CLASSIFICATION
GROUP 1	
BOGOTA, COLUMBIA. . . . . .TIBAITATA SERIES	
HOLETTA, ETHIOPIA . . . . .EUTRIC NITOSOL (UDALF)	
NJORO, KENYA	
MEXICO CITY, MEXICO	
GROUP 2	
GEMBLOUX, BELGIUM . . . . .HAPLUDALF: SOL BRUN LESSIVE SUR LIMON	
LELYSTAD, NETHERLANDS . . . . . .MEDIUM CLAY	
RILLAND, NETHERLANDS. . . . . . .MEDIUM LIGHT MARINE CLAY	
LINCOLN, UNITED KINGDOM . . . . .JURASSIC CHALK	
COPENHAGEN, DENMARK	
ROSKILDE, DENMARK	
GROUP 3	
CORK, IRELAND . . . . .ACID BROWN EARTHS	
DUBLIN, IRELAND . . . . .GREY-BROWN PODZOLIC	
EDINBURGH, UNITED KINGDOM . . . .BROWN CALCAREOUS AND BROWN FOREST SOILS	
GROUP 4	
HAMAR, NORWAY . . . . .CAMBISOLS	
GOTTINGEN, WEST GERMANY . . . . .DEGRADED LOESS	
OSLO, NORWAY	
GROUP 5	
KROMERIZ, CZECHOSLOVAKIA. . . . .EUROPEAN BROWN SOIL	
RINGSTED, DENMARK . . . . .HUMUS RICH, MEDIUM SANDY CLAY	
GOETTINGEN, WEST GERMANY. . . . .BROWN EARTH	
GORZOW, POLAND	
GROUP 6	
MOSCOW, USSR. . . . . .FOREST PODZOLIC	
HAMEENLINNA, FINLAND	
HELSINKI, FINLAND	
KOUVOLA, FINLAND	

TABLE 3: CONTINUED.

GROUP NUMBER AND LOCATION	SOIL CLASSIFICATION
GROUP 7	
PALMER, ALASKA.	TYPIC CRYORTHENT, COARSE-SILTY OVER SANDY OR SANDY-SKELETAL, MIXED, NONACID
BEAVERLODGE, ALBERTA.	DARK GRAY SOLOD (GLOSSIC NATRIBORALF)
EDMONTON, ALBERTA	ELUVIATED BLACK CHERNOZEM (UDIC ARGIBOROLL)
LANDSKRONA, M. L., SWEDEN . . . LANDSKRONA, SWEDEN	MEDIUM MORAINE CLAY
GROUP 8	
CLERMONT-FERRAND, FRANCE. . . .	CALCAREOUS BROWN SOIL
FONTAINEBLEAU, FRANCE	LIMONS EOLIENS
MAULE, FRANCE	LIMON ARGILO-CALCAIRE
ABERYSTWYTH, UNITED KINGDOM . .	BROWN EARTH
GROUP 9	
LAFAYETTE, INDIANA.	TYPIC ARGIAQUOLL, FINE-LOAMY, MIXED, MESIC
LINCOLN, NEBRASKA	TYPIC ARGIUDOLL, FINE, MONTMORILLONITIC, MESIC
GROUP 10	
BUDAPEST, HUNGARY	PRE-DANUBIAN LOAMY CHERNOZEM
GUELPH, ONTARIO	MELANIC BRUNISOL ((MOLLIC) EUTROCHREPT)
OTTAWA, ONTARIO	REGO HUMIC GLEYSOL (TYPIC AQUOLL OR TYPIC HUMAQUEPT)
MACDONALD COLLEGE, QUEBEC . . .	CHATEAUQUAY SERIES
ST. PAUL, MINNESOTA	AQUIC FRAGIOCHREPT, COARSE-LOAMY, MIXED, FRIGID
	TYPIC (GLOSSIC) EUTROBORALF, FINE, MIXED
	TYPIC FRAGIOCHREPT, COARSE-LOAMY, MIXED, FRIGID
	DYSTRIC EUTROCHREPT, COARSE-LOAMY, MIXED, FRIGID

TABLE 3: CONTINUED.

GROUP NUMBER AND LOCATION	SOIL CLASSIFICATION

GROUP 11
FORT COLLINS, COLORADO. . . . . . .ARIDIC ARGIUSTOLL, FINE, MONTMORILLONITIC,
                                      MESIC
ABERDEEN, IDAHO . . . . .XEROLLIC CALCIORTHID, COARSE-LOAMY,
                                            MIXED, MESIC

GROUP 12
LETHBRIDGE, ALBERTA . . . .DARK BROWN CHERNOZEM (TYPIC BOROLLS)
BOZEMAN, MONTANA. . . . . .ARGIC CRYOBOROLL, FINE-SILTY, MIXED
MOCCASIN, MONTANA . . . . .TYPIC ARGIBOROLL, FINE, MONTMORILLONITIC
                              TYPIC CALCIBOROLL, FINE-LOAMY, CARBONATIC

GROUP 13
SIDNEY, MONTANA . . . . .TYPIC ARGIBOROLL, FINE-SILTY, MIXED
FARGO, NORTH DAKOTA . . . . . . .VERTIC HAPLAQUOLL, FINE, MONTMORILLONITIC,
                                       FRIGID
BROOKINGS, SOUTH DAKOTA . . . . .UDIC HAPLOBOROLL, FINE-LOAMY, MIXED

GROUP 14
BRANDON, MANITOBA . . . . .BLACK CHERNOZEM (CALCIBOROLL)
WINNIPEG, MANITOBA. . . . . . . .GLEYED REGO BLACK (UDIC HAPLOBOROLL)
SASKATOON, SASKATCHEWAN . . . . .CHERNOZEMIC DARK BROWN (TYPIC BOROLLS)

GROUP 15
COLUMBIA, MISSOURI. . . . . . . .UDOLLIC OCHRAQUALF, FINE, MONTMORILLONITIC,
                                      MESIC
ITHACA, NEW YORK. . . . . .AERIC OCHRAQUALF, FINE-SILTY, MIXED, MESIC
AMES, IOWA. . . . . .UDIC HAPLUDOLL, FINE-LOAMY, MIXED, MESIC
                              TYPIC ALBAQUALF, FINE, MONTMORILLONITIC,
                                      MESIC
                              TYPIC HAPLAQUOLL, FINE-LOAMY, MIXED, MESIC

GROUP 16
PENDLETON, OREGON . . . . .TYPIC HAPLOXEROLL, COARSE-SILTY, MIXED,
                                      MESIC
LOGAN, UTAH . . . . .TYPIC HAPLOXEROLL, COARSE-SILTY,
                                      CARBONATIC MESIC
PULLMAN, WASHINGTON . . . . . . .PACHIC ULTIC HAPLOXEROLL, FINE-SILTY,
                                      MIXED, MESIC

TABLE 3: CONTINUED.

GROUP NUMBER AND LOCATION	SOIL CLASSIFICATION

GROUP 17
WALEUP, VICTORIA, AUSTRALIA . . . .SOLONIZED BROWN SOIL (HAPLARGID)
HUNTLEY, MONTANA. . . . . .USTOLLIC HAPLARGID, FINE-LOAMY, MIXED,
                                                                    MESIC
                                        USTIC TORRIFLUVENT, FINE, MONTMORILLONITIC,
                                                                    CALCAREOUS, MESIC

GROUP 18
MESA, ARIZONA . . . . .TYPIC CALCIORTHID, COARSE-LOAMY, MIXED
                                                                    HYPERTHERMIC

CAIRO, A. R. OF EGYPT . . . . . .NILE ALLUVIUM
LYALLPUR, PAKISTAN. . . . . . . .BAHLVAL 5
PESHAWAR, PAKISTAN. . . . . . . .TARNAB ASSOCIATION
TANDOJAM, PAKISTAN. . . . . . . .SHAHDERA
KHARTOUM, SUDAN . . . . .NILE VALLEY ALLUVIUM
ABU-GHRIAB, IRAQ
SALT, JORDAN

GROUP 19
TRAYNING, W. A., AUSTRALIA. . . .SOLONIZED BROWN SOIL (XERALF)
WAGGA WAGGA, N.S.W., AUSTRALIA. .RED EARTH (ALFISOL)
WERRIBEE, VICTORIA, AUSTRALIA . .RED BROWN EARTH (HAPLOXERALF)
WONGAN HILLS, W. A. AUSTRALIA . .LATERITIC PODZOLIC (ALFISOL)
RABAT, MOROCCO. . . . . .PSAMMENTIC OR TYPIC RHODOXERALF, THERMIC
ELVAS, PORTUGAL . . . . .BROWN SOIL
MADRID, SPAIN . . . . .HAPLOXERALF
ADELAIDE, S. A., AUSTRALIA
THESSALONIKI, GREECE

GROUP 20
DAVIS, CALIFORNIA . . . . .TYPIC XEROCHREPT, FINE-SILTY, MIXED,
                                                                    THERMIC

IZMIR, TURKEY . . . . .ALLUVIAL
BEDJA, TUNISIA

GROUP 21
CASTELAR, ARGENTINA . . . . . . .BRUNIZEM (UDOLL)
TRES ARROYOS, ARGENTINA . . . . .ARGIUDOLES OR ARGIUDOLES PETROCALCIONS
MONTPELLIER, FRANCE . . . . . . .SOL BRUN CALCAIRE SUR ALLUVIONS ET TUFS

TABLE 3: CONTINUED.

GROUP NUMBER AND LOCATION	SOIL CLASSIFICATION
GROUP 22	
STILLWATER, OKLAHOMA.	.UDERTIC PALEUSTOLL, FINE, MIXED, THERMIC
ZARAGOZA, SPAIN	.BROWN SOIL WITH PETROCALCIC HORIZON
GROUP 23	
TEL-AMARA, LEBANON.	.SOL MARRON
ZAHLE, LEBANON.	.VERTIC XEROCHREPT
STELLENBOSCH, SO. AFRICA.	.WESTLEIGH
GROUP 24	
SAMISTIPUR, INDIA	.ALLUVIAL SOILS
VARANASI, INDIA	.ALLUVIAL SOILS
NEW DELHI, INDIA	
GROUP 25	
CHIKUGO, JAPAN.	.GRAY-BROWN SOIL
KOUNOSU CITY, JAPAN	.ALLUVIAL SOIL
TOCHIGI-CITY, JAPAN	.FULVIC HAPLAQUEPT
TOKYO, JAPAN.	.ALLUVIAL, HALF-BOG SOIL
ZENTSUJI, JAPAN	.ALLUVIAL SOIL
WARSAW, VIRGINIA.	.TYPIC HAPLUDULT, FINE-LOAMY, SILICEOUS, MESIC
ATHENS, GEORGIA	.TYPIC HAPLUDULT, COARSE-LOAMY, MIXED, THERMIC
SINGLE-MEMBER GROUPS	
A. BOURGAS, BULGARIA.	.LEACHED CHERNOZEM SMOLNITZA
B. NICOSIA, CYPRUS.	.CALCARIC REGOSOL
C. CAMBRIDGE, ENGLAND	
D. BUCHAREST, ROMANIA	.CHERNOZEM
E. ZURICH, SWITZERLAND	
F. WORONEZSKAJ REG., USSR	.BLACK EARTH
G. STRAUBING, WEST GERMANY. . . .	.LOESS
H. HAVRE, MONTANA	.ARIDIC ARGIBOROLL, FINE-LOAMY, MIXED
I. KALISPELL, MONTANA	.UDIC HAPLOBOROLL, COARSE-SILTY, MIXED TYPIC EUTROCHREPT, FINE-SILTY, MIXED, FRIGID
J. CORVALLIS, OREGON.	.AQUULTIC ARGIXEROLL, FINE-SILTY, MIXED, MESIC
K. DENTON, TEXAS.	.UDIC PELLUSTERT, FINE, MONTMORILLONITIC, THERMIC TYPIC USTOCHREPT, LOAMY, CARBONATIC, THERMIC, SHALLOR VERTIC CALCIUSTOLL, CLAYEY, MONTMORILLONITIC, THERMIC LITHIC CALCIUSTOLL, CLAYEY, MONTMORILLONITIC, THERMIC
L. MADISON, WISCONSIN	.TYPIC HAPLUDALF, FINE-LOAMY, MIXED, MESIC
M. LARAMIE, WYOMING	.ARGIC CRYOBOROLL, FINE-LOAMY OVER SAND OR SANDY-SKELETAL, MIXED

TABLE 4: NORTH AMERICAN CENTERS GROUPED BY GROWING SEASON VARIABLES.

GROUP NUMBER AND LOCATION	GROUP NUMBER AND LOCATION

1. FORT COLLINS, COLORADO (S)
   ABERDEEN, IDAHO (S)
   HUNTLEY, MONTANA (S)
   LOGAN, UTAH (S)
   *HAVRE, MONTANA (S)
	10. ATHENS, GEORGIA (W)
	    STILLWATER, OKLAHOMA (W)
	    WARSAW, VIRGINIA (W)
	    *DENTON, TEXAS (W)

2. BOZEMAN, MONTANA (S)
   LARAMIE, WYOMING (S)
	11. LAFAYETTE, INDIANA (W)
	    COLUMBIA, MISSOURI (W)
	    LINCOLN, NEBRASKA (W)
	    ITHACA, NEW YORK (W)

3. AMES, IOWA (S)
   LINCOLN, NEBRASKA (S)
	12. PULLMAN, WASHINGTON (W)
	    PENDLETON, OREGON (W)

4. OTTAWA, ONTARIO (S) MACDONALD COLLEGE, QUEBEC (S)	SINGLE-MEMBER GROUPS
5. MADISON, WISCONSIN (S) GUELPH, ONTARIO (S)	A. PALMER, ALASKA (S)
	B. MESA, ARIZONA (W)

6. *FARGO, NORTH DAKOTA (S)
   WINNIPEG, MANITOBA (S)
   BRANDON, MANITOBA (S)
	C. SIDNEY, MONTANA (S)

	D. CORVALLIS, OREGON (S)

7. LETHBRIDGE, ALBERTA (S)
   KALISPELL, MONTANA (S)
   MOCCASIN, MONTANA (S)
	E. PENDLETON, OREGON (S)

	F. BROOKINGS, SOUTH DAKOTA (S)

8. BEAVERLODGE, ALBERTA (S)
   EDMONTON, ALBERTA (S)
   *SASKATOON, SASKATCHEWAN (S)
	G. PULLMAN, WASHINGTON (S)

	H. ST. PAUL, MINNESOTA (S)
9. *DAVIS, CALIFORNIA (W) *CORVALLIS, OREGON (W)	

S: Spring barley center
W: Winter barley center
*   Added to group after stepwise discriminant analysis

TABLE 5: CLUSTER ANALYSIS OF MONTANA CENTERS GROUPED BY GROWING
          SEASON VARIABLES IN A STEPWISE MANNER.

GROUPINGS BY STEPS	GROUPINGS BY STEPS
1ST STEP	3RD STEP
A. MOCCASIN, KALISPELL	A. BOZEMAN, MOCCASIN, KALISPELL

B. SINGLE-MEMBER GROUPS
     BOZEMAN
     HAVRE
     HUNTLEY
     SIDNEY
	B. HAVRE, SIDNEY
	
	C. SINGLE-MEMBER GROUP
	     HUNTLEY

2ND STEP	4TH STEP
A. MOCCASIN, KALISPELL	A. BOZEMAN, MOCCASIN, KALISPELL, HAVRE, SIDNEY
B. HAVRE, SIDNEY	B. SINGLE-MEMBER GROUP HUNTLEY

C. SINGLE-MEMBER GROUPS
     BOZEMAN
     HUNTLEY
	5TH STEP
	
	ALL SIX MONTANA CENTERS IN ONE GROUP.

Results of Questionnaire and Other Analyses

The questionnaires returned from barley breeders contained soil

texture names or percentages of sand, silt, and clay. These data

were plotted on textural triangles in Figures 3 and 4 to illustrate

the distribution of soil textures at barley breeding centers.

Average planting and harvest dates of barley were collected in

the questionnaires. For North American centers the average length

of barley growing season was computed. The average growing season

lengths were divided by three to derive dates for the end of the

first third and end of the second third of the growing season at

North American centers (See Table 6).

A computer program supplied by Dr. J. M. Caprio was used to com-

pute solar-thermal unit data for North American centers. Using grow-

ing season dates from Table 6, cumulative solar-thermal unit data

during the growing season at North American centers were computed

(See Table 7).

A three-dimensional model prepared using the growing season

variables of Montana centers is illustrated in Figure 5. Each center,

represented by a white ball, was assigned a point in the model based

on values of its environmental variables.

Table 8 contains OAC and Parkland barley yield data collected

from 5 breeding centers in the Canadian Western Cooperative Barley

Nursery. Tables 9-12 show results of factorial analysis of this data.
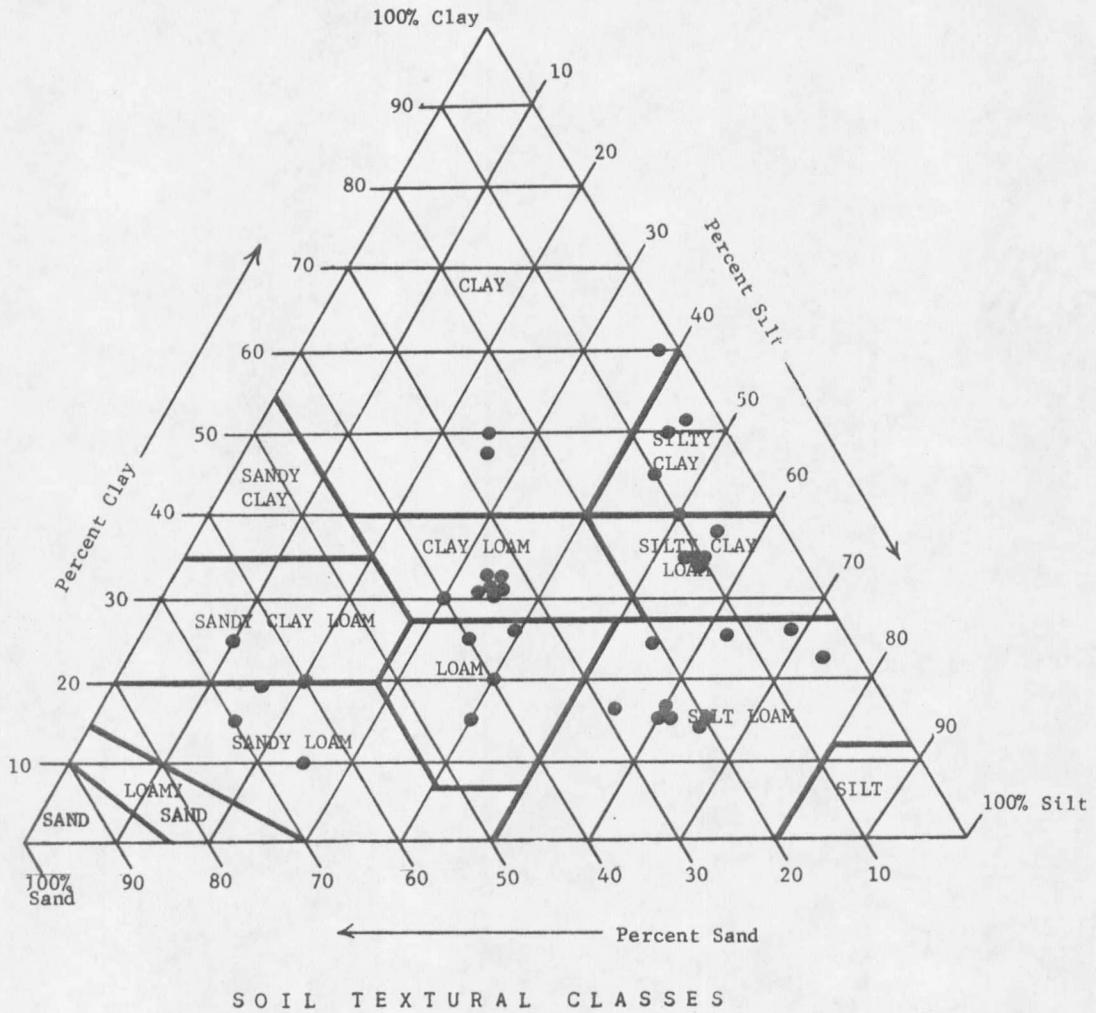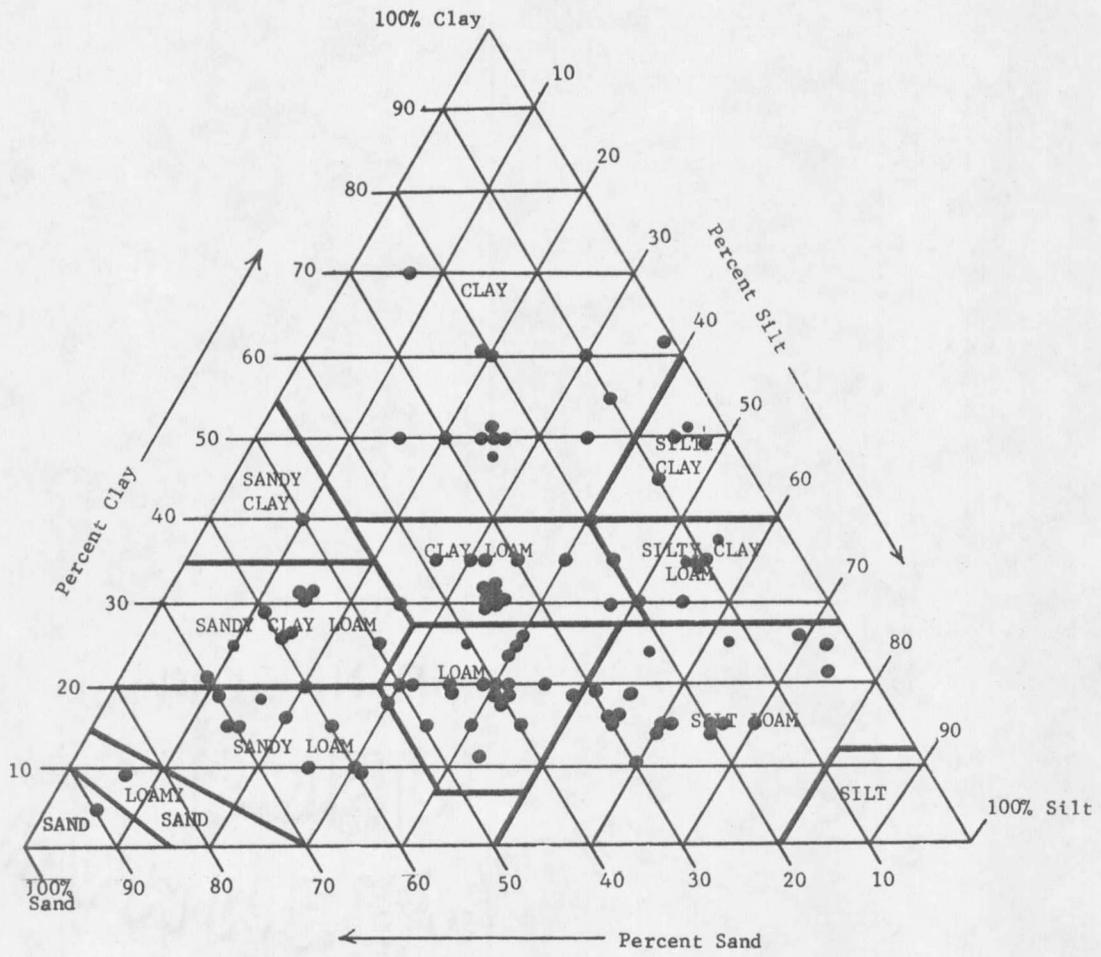
SOIL TEXTURAL CLASSES

FIGURE 3: SOIL TEXTURES OF NORTH AMERICAN BARLEY BREEDING CENTERS.

SOIL TEXTURAL CLASSES

FIGURE 4: SOIL TEXTURES OF WORLD BARLEY BREEDING CENTERS.

TABLE 6: SPRING AND WINTER BARLEY GROWING SEASON DATES OF NORTH AMERICAN CENTERS.

| | GROWING SEASON DATES | | | | |
SITE	PLANTING	END FIRST THIRD	END SECOND THIRD	HARVEST	AVERAGE LENGTH OF GROWING SEASON
SPRING					
PALMER, ALASKA	5/8	6/13	7/18	8/22	105
FORT COLLINS, COLORADO	4/1	5/5	6/10	7/15	105
ABERDEEN, IDAHO	4/12	5/18	6/24	8/1	108
AMES, IOWA	4/9	5/11	6/13	7/15	96
ST. PAUL, MINNESOTA	4/25	5/25	6/25	7/25	90
LINCOLN, NEBRASKA	4/1	5/4	6/7	7/10	99
FARGO, NORTH DAKOTA	4/30	5/30	6/29	7/28	90
CORVALLIS, OREGON	4/8	5/19	6/30	8/10	123
PENDLETON, OREGON	4/1	5/5	6/10	7/14	102
BROOKINGS, SOUTH DAKOTA	4/20	5/22	6/23	7/25	96
LOGAN, UTAH	4/12	5/18	6/16	8/4	87
PULLMAN, WASHINGTON	4/10	5/17	6/24	8/1	111
MADISON, WISCONSIN	4/20	5/23	6/25	7/28	99
LARAMIE, WYOMING	4/15	5/25	7/5	8/15	120
MACDONALD COLLEGE, QUEBEC	5/5	6/7	7/8	8/10	96
OTTAWA, ONTARIO	5/5	6/3	7/2	8/1	87
GUELPH, ONTARIO	5/1	6/2	7/4	8/5	96
WINNIPEG, MANITOBA	5/15	6/15	7/15	8/15	90
BRANDON, MANITOBA	5/15	6/14	7/13	8/12	87
BEAVERLODGE, ALBERTA	5/10	6/17	7/25	9/1	117
EDMONTON, ALBERTA	5/10	6/13	7/16	8/20	99
LETHBRIDGE, ALBERTA	5/7	6/11	7/16	8/20	105
SASKATOON, SASKATCHEWAN	5/22	6/21	7/21	8/20	90
BOZEMAN, MONTANA	5/5	6/10	7/15	8/20	105
HAVRE, MONTANA	4/25	5/31	7/6	8/10	108
HUNTLEY, MONTANA	4/10	5/15	6/19	7/25	105
KALISPELL, MONTANA	4/25	5/31	7/6	8/10	108
MOCCASIN, MONTANA	4/20	5/25	7/1	8/5	105
SIDNEY, MONTANA	5/10	6/12	7/14	8/15	96
WINTER					
MESA, ARIZONA	12/1	1/20	3/11	5/1	150
DAVIS, CALIFORNIA	12/10	2/6	4/2	5/28	168
ATHENS, GEORGIA	10/25	1/5	3/16	5/28	213
LAFAYETTE, INDIANA	9/20	12/23	3/26	6/30	279
COLUMBIA, MISSOURI	9/20	12/17	3/14	6/10	261
LINCOLN, NEBRASKA	9/25	12/25	3/25	6/25	270
ITHACA, NEW YORK	9/15	12/25	4/5	7/15	300
STILLWATER, OKLAHOMA	10/15	1/3	3/22	6/10	234
CORVALLIS, OREGON	10/15	1/18	4/21	7/25	279
PENDLETON, OREGON	10/15	1/12	4/9	7/7	261
DENTON, TEXAS	10/20	1/4	3/17	6/1	219
WARSAW, VIRGINIA	10/10	1/2	3/24	6/15	246
PULLMAN, WASHINGTON	9/20	12/27	4/4	7/10	291

TABLE 7: CUMULATIVE SOLAR-THERMAL UNITS AT DATES DURING SPRING AND WINTER BARLEY GROWING SEASON OF NORTH AMERICAN CENTERS.

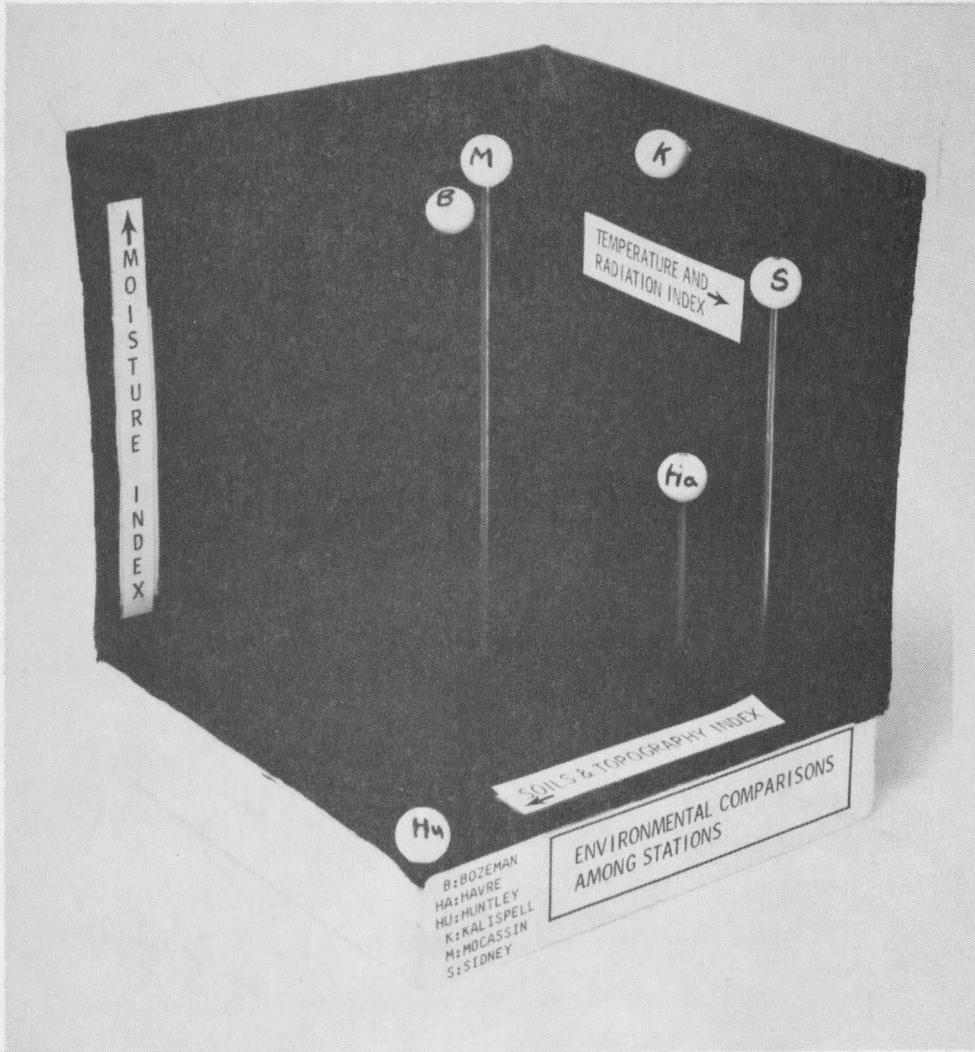| SITE		GROWING SEASON DATES		
	PLANTING	END FIRST THIRD	END SECOND THIRD	HARVEST
SPRING				
PALMER, ALASKA	0	308164	694519	997575
FORT COLLINS, COLORADO	0	295438	944246	1806494
ABERDEEN, IDAHO	0	328500	1014493	1896533
AMES, IOWA	0	295392	848733	1568146
ST. PAUL, MINNESOTA	0	357023	928386	1599989
LINCOLN, NEBRASKA	0	280947	816179	1572314
FARGO, NORTH DAKOTA	0	370800	938089	1578148
CORVALLIS, OREGON	0	412539	1109080	2004476
BROOKINGS, SOUTH DAKOTA	0	290295	794220	1457166
LOGAN, UTAH	0	396458	940590	2123545
PULLMAN, WASHINGTON	0	341720	903985	1733038
MADISON, WISCONSIN	0	311315	906618	1623680
LARAMIE, WYOMING	0	285069	919942	1670465
MACDONALD COLLEGE, QUEBEC	0	430561	1020645	1662795
OTTAWA, ONTARIO	0	368604	909463	1509424
GUELPH, ONTARIO	0	339712	878558	1488480
WINNIPEG, MANITOBA	0	409636	958778	1513885
BRANDON, MANITOBA	0	384867	886501	1411686
BEAVERLODGE, ALBERTA	0	406412	939465	1355704
EDMONTON, ALBERTA	0	385621	872629	1341718
LETHBRIDGE, ALBERTA	0	418409	1045728	1672938
SASKATOON, SASKATCHEWAN	0	406268	928917	1384322
BOZEMAN, MONTANA	0	383380	942506	1541043
HAVRE, MONTANA	0	399440	1079444	1841675
HUNTLEY, MONTANA	0	307404	886350	1731348
KALISPELL, MONTANA	0	369289	961247	1645025
MOCCASIN, MONTANA	0	302691	873510	1588968
SIDNEY, MONTANA	0	540592	1285486	2013775
WINTER				
MESA, ARIZONA	0	352609	849169	1871919
DAVIS, CALIFORNIA	0	158310	596322	1641748
ATHENS, GEORGIA	0	331308	728786	1995975
LAFAYETTE, INDIANA	0	373025	412844	1730290
COLUMBIA, MISSOURI	0	514504	581991	1747498
LINCOLN, NEBRASKA	0	344967	434565	1695805
ITHACA, NEW YORK	0	316864	357248	1652207
STILLWATER, OKLAHOMA	0	308801	580089	1893770
CORVALLIS, OREGON	0	171123	516249	2080930
PENDLETON, OREGON	0	141582	392649	1789973
DENTON, TEXAS	0	475311	881056	2261451
WARSAW, VIRGINIA	0	304529	526245	1738758
PULLMAN, WASHINGTON	0	282990	409015	1678202

FIGURE 5:   THREE-DIMENSIONAL MODEL ILLUSTRATING ENVIRONMENTAL
COMPARISONS AMONG MONTANA BARLEY BREEDING CENTERS.

TABLE 8: OAC AND PARKLAND BARLEY VARIETY YIELDS AT BARLEY BREEDING CENTERS IN THE WESTERN COOPERATIVE BARLEY NURSERY - CANADA.

	Brandon		Winnipeg		Beaverlodge		Edmonton		Saskatoon	
Year	OAC	Parkland	OAC	Parkland	OAC	Parkland	OAC	Parkland	OAC	Parkland
					bu/A					
1959	65.0	73.1	62.5	65.4	38.8	49.3	50.5	53.0	25.0	32.9
1960	44.6	40.6	64.0	70.0	62.8	67.4	49.5	52.0	34.0	44.9
1961	33.0	40.8	35.7	47.6	71.6	97.7	35.4	50.2	17.2	25.5
1962	57.7	88.9	*	*	35.4	48.1	62.3	87.0	14.2	28.5
1963	59.8	62.4	50.6	49.1	20.6	25.6	59.7	59.7	65.9	77.4
1964	59.0	75.5	70.8	75.6	*	*	54.5	76.9	20.8	24.3
1965	61.9	65.8	69.4	71.3	52.7	57.8	38.2	38.7	64.0	87.4
1966	58.7	63.9	45.4	52.1	*	*	37.9	46.7	61.5	65.4
1967	59.1	67.0	89.3	98.1	53.1	63.5	75.8	91.9	38.3	52.1
1968	59.7	64.7	76.4	79.4	82.5	84.4	72.5	95.2	54.6	62.9

* Data missing.

TABLE 9: FACTORIAL ANALYSIS FOR YEARS, VARIETIES, AND CENTERS
(BRANDON, WINNIPEG).

Source	Degrees of Freedom	Mean Squares
Years	8	553.10 *
Varieties	1	264.06 *
Centers	1	387.43 *
Varieties X Centers	1	2.01
Error	24	82.78

* Significant at the .05 level.

TABLE 10: FACTORIAL ANALYSIS FOR YEARS, VARIETIES, AND CENTERS
(BRANDON, WINNIPEG).

Source	Degrees of Freedom	Mean Squares
Years	7	456.97 *
Varieties	1	204.01
Centers	1	100.80
Varieties X Centers	1	2.79
Error	21	63.01

* Significant at the .05 level.

TABLE 11: FACTORIAL ANALYSIS FOR YEARS, VARIETIES, AND CENTERS
(BEAVERLODGE, EDMONTON, SASKATOON).

Source	Degrees of Freedom	Mean Squares
Years	7	670.36
Varieties	1	1389.98
Center··	2	1032.87
Varieties X Centers	2	7.74
Error	35.	375.75

TABLE 12: FACTORIAL ANALYSIS FOR YEARS, VARIETIES, AND CENTERS
(BRANDON, WINNIPEG, BEAVERLODGE, EDMONTON, SASKATOON).

Source	Degrees of Freedom	Mean Squares
Years	5	2953.38 *
Varieties	1	764.69 *
Centers	4	306.14 *
Varieties X Centers	4	33.72
Error	45	57.99

* Significant at the .05 level.

DISCUSSION

North American Centers Grouped By Year-Round Variables

Similarities in soil classification at the suborder level in Soil Taxonomy (32) exist within groups 1, 2, 3, 4, 5, and 8. Similarity in soil classification at the subgroup level in Soil Taxonomy exists within group 7. The centers in group 6, although not having the same soil classification, grouped together due to location and temperature similarities.

An examination of the soil classifications of the single-member groups shows why they were not assigned into a group by the analyses. Huntley is warmer (mesic temperature regime) than other North American centers at similar latitudes. Mesa is hotter (hyperthermic) and drier (Aridisol) than other North American centers. Davis has a combination of hot temperatures (thermic) and seasonal differences in precipitation (xeric) which is different from other North American centers. Stillwater is hot (thermic) and dry (ustic). Denton is hot (thermic) and dry (ustic).

Inspection of Stillwater and Denton soil classifications would suggest that they be grouped. However, close examination of the temperature and precipitation data collected from the questionnaires showed that Stillwater is colder throughout the year than Denton. Precipitation distribution between centers is also different.

One interesting feature of the North American centers grouped by year-round variables is that the same soil subgroup name occurs in

three different groups. For example:

Group 1

      Kalispell, Montana: Udic Haploboroll, coarse-silty, mixed

Group 2

      Brookings, South Dakota: Udic Haploboroll, fine-loamy, mixed

Group 3

      Winnipeg, Manitoba: Udic Haploboroll, (Gleyed Rego Black).

This suggests that the soil moisture regime (udic) and temperature

regime (frigid) used in Soil Taxonomy (32) are not refined enough to

differentiate precipitation and temperature distributions which

apparently caused these centers to separate into different groups.

Another inference could be that the three groups (1, 2, 3) should

have been clustered by the analyses and that their division into

separate groups was arbitrary. Indeed, at a lower level of

differentiation, all centers in these three groups did cluster.

An examination of the common soil and climatic characteristics of

each North American group in Table 2 shows that most centers within

each group have similar temperature and moisture regimes. They also

have other soil properties in common. Since most of the environmental

variables were climate-related and because climate is an important

factor of soil formation, centers within a group would be expected

to have several common soil properties.

World Centers Grouped By Year-Round Variables

Soil classification information was incomplete for the world

centers. When soil classification names were available, no adequate

correlation with Soil Taxonomy (32) could be derived from the

references (10, 11, 22, 27, 35) in many cases.

There is a need for increased inventory of soils information from

world centers that can be correlated with a widely recognized classi-

fication such as Soil Taxonomy. When this information is collected,

all world groups could be characterized according to similar climatic

and soil properties.

Where sufficient data were available for a group, common charac-

teristics of that group could be listed. For example, within group

19 are centers from Africa, Europe, and Australia. The soil order

Alfisol, or suborder Xeralf, was dominant in this group. With the

use of Soil Taxonomy (32), the following characteristics common to

Group 19 were listed: 1) the soils have a light-colored surface

horizon, 2) there has been downward movement of clays in the soil and

an accumulation of clay in a subsurface horizon, 3) the soils have

moderate to high base saturation in the surface horizon, 4) soils are

dry for extended periods in summer, but in many of them moisture moves
in winter to subsurface horizons most years, 5) the mean annual soil
temperature is less than 22°C (72°F).

All world groups could be characterized in this way if sufficient
soil classification information was available.

Most of the North American centers clustered in the same groups
in Table 2 as they had previously clustered in Table 1. Some single-
member North American centers (Table 1) are grouped with world centers.
These centers include Davis (group 20), Huntley (group 17), Mesa (group
18), and Stillwater (group 22). Other North American centers, in
groups in Table 1 (Corvallis, Havre, Kalispell, Laramie, and Madison),
were single-member groups in the world groupings. This occurred
because the stepwise discriminant analysis was not used.

North American Centers Grouped By Growing Season Variables

Centers within a group should be able to exchange variety yield
results if all variables important for determining yield were used
in the analyses.

Factorial analysis of yields showed that centers in group 8 (i.e.
Edmonton, Beaverlodge, and Saskatoon) were not significantly different.

The analysis did show centers in group 6 (i.e. Brandon and
Winnipeg) to be significantly different when 9 years of variety yield
information were used. However, when abnormal 1967 yield data were
eliminated from the analysis, the two centers were not significantly

different. A close examination of 1967 climatological data helped explain these results. Total precipitation, April through September at Winnipeg and Brandon was 11.99 inches and 7.40 inches, respectively. This was near normal for Winnipeg but 8.57 inches below normal for Brandon. In addition, July precipitation at Winnipeg was 3.45 inches, about one inch above normal. This may explain part of the yield differences between the two centers in 1967.

When all 5 Canadian centers from groups 6 and 8 were considered together in factorial analysis, they were significantly different.

The results of these analyses are inconclusive. They demonstrate a need for additional inventory of environmental and crop yield data from centers. This information could be used in cluster analysis to group environmentally analogous centers for purposes of yield data and crop germplasm exchange.

Montana Centers Grouped By Growing Season Variables

Montana centers were grouped using different growing season variables than those used to group North American centers.

The three-dimensional model shown in Figure 4 illustrates environmental differences and similarities among Montana stations. For example, the model shows Moccasin and Kalispell similar in temperature, radiation, and moisture and the centers grouped in the first step of the cluster analysis. Huntley, quite different from other centers, was a single member until the last step of the cluster analysis.

The primary purpose for comparing the model with the cluster analysis was to demonstrate the limitations of cluster analysis. Although cluster analysis grouped environmentally similar centers, it did not show which variables caused centers to group. Examination of the three-dimensional model identified these variables.

CONCLUSIONS AND RECOMMENDATIONS

Soil classification similarities exist among North American and world centers grouped by cluster analysis. This demonstrates that land classification by Soil Taxonomy (32) or by readily available climatic factors gives similar results.

North American centers, grouped by growing season variables, were compared by factorial analysis of barley yield data. The results were inconclusive. They showed centers within groups were both significantly different and not significantly different, depending on the data used.

The three-dimensional model, prepared with growing season information for Montana centers, facilitated comparisons among centers. The model supplemented cluster analysis by illustrating the environmental variables which caused centers to group.

Recommendations for further study include: 1) identify environmental variables that determine barley yield; 2) group world barley breeding centers by growing season environmental variables; 3) inventory additional environmental and crop yield data from barley breeding centers and secondary testing sites; 4) produce environmental maps to illustrate relationships among world barley breeding centers.

APPENDIX

APPENDIX TABLE 13: QUESTIONNAIRE SENT TO WORLD BARLEY BREEDERS.

TITLE: ENVIRONMENTS OF WORLD BARLEY BREEDING CENTERS*

NAME OF NURSERY: _____

NAME OF COOPERATOR: _____

LOCATION OF NURSERY: COUNTRY _____

                                STATE OR PROVINCE _____

                                NEAREST CITY OR TOWN _____

                                LATITUDE _____

                                LONGITUDE _____

                                ELEVATION _____

AVERAGE DATE OF BARLEY PLANTING _____

AVERAGE DATE OF BARLEY HARVEST _____

AVERAGE MONTHLY PRECIPITATION:

JANUARY _____ mm	JULY _____ mm
FEBRUARY _____ mm	AUGUST _____ mm
MARCH _____ mm	SEPTEMBER _____ mm
APRIL _____ mm	OCTOBER _____ mm
MAY _____ mm	NOVEMBER _____ mm
JUNE _____ mm	DECEMBER _____ mm

MEAN MONTHLY MAXIMUM TEMPERATURE:

JANUARY _____ ^{o}C	JULY _____ ^{o}C
FEBRUARY _____ ^{o}C	AUGUST _____ ^{o}C
MARCH _____ ^{o}C	SEPTEMBER _____ ^{o}C
APRIL _____ ^{o}C	OCTOBER _____ ^{o}C
MAY _____ ^{o}C	NOVEMBER _____ ^{o}C
JUNE _____ ^{o}C	DECEMBER _____ ^{o}C

* THIS QUESTIONNAIRE APPLIES ONLY TO YOUR MAIN EXPERIMENTAL CENTER.

APPENDIX TABLE 13: CONTINUED.

MEAN MONTHLY MINIMUM TEMPERATURE:

JANUARY _____ °C   JULY _____ °C

FEBRUARY _____ °C   AUGUST _____ °C

MARCH _____ °C   SEPTEMBER _____ °C

APRIL _____ °C   OCTOBER _____ °C

MAY _____ °C   NOVEMBER _____ °C

JUNE _____ °C   DECEMBER _____ °C

CONDITIONS UNDER WHICH BARLEY BREEDING IS CONDUCTED (CHECK ONE OR BOTH):

    IRRIGATED   ☐   DRYLAND   ☐

AVERAGE TOTAL IRRIGATION WATER APPLIED DURING GROWING SEASON _____ cm

PREDOMINANT CROPPING METHODS (CHECK ONE):

   ALTERNATE CROP-FALLOW ☐ CONTINUOUS CROPPING ☐ ROTATION ☐

FERTILIZERS COMMONLY APPLIED:

   NONE ☐   COMMERCIAL ☐   MANURE ☐

WHAT BARLEY VARIETIES HAVE BEEN RELEASED FROM YOUR STATION, AND WHAT ARE

THE DATES OF RELEASE?

VARIETY	DATE	VARIETY	DATE
_____	____	_____	____
_____	____	_____	____
_____	____	_____	____
_____	____	_____	____
_____	____	_____	____

APPENDIX TABLE 13: CONTINUED.

ARE THERE SECONDARY TESTING SITES WHERE EARLY GENERATION MATERIAL IS
EVALUATED? IF SO, PLEASE LIST.

SITE	NEAREST CITY OR TOWN	SITE	NEAREST CITY OR TOWN
____	_____	____	_____
____	_____	____	_____
____	_____	____	_____

SOIL INFORMATION:

SOIL CLASSIFICATION _____

DOMINANT SOIL SERIES NAME _____

TEXTURE NAME _____

    OR

ESTIMATED PERCENT SAND, SILT AND CLAY OF UPPER 20 cm.

                                    SAND _____ %

                                    SILT _____ %

                                    CLAY _____ %

PHYSIOGRAPHY OF SITE (CHECK ONE):

☐ BASINS, PLAYAS, AND OLD LAKE BEDS

☐ FLOODPLAINS, INCLUDING BOTTOM LANDS AND STREAM BOTTOMS

☐ STREAM TERRACES

☐ FANS, BOTH ALLUVIAL AND COLLUVIAL

☐ LEVEL AND UNDULATING PLAINS AND PLATEAUS

☐ ROLLING AND HILLY PLAINS AND PLATEAUS

☐ MOUNTAINS, STEEP HILLS, AND DEEPLY DISSECTED PLATEAUS

LITERATURE CITED

1. Anonymous. 1974. CIMMYT Review. 93 p.

2. Aspinall, D. 1966. Effects of daylength and light intensity on growth of barley. Genetically controlled variation in response to photoperiod. Aust. J. Biol. Sci. 19:517-534.

3. Biomedical Computer Programs. 1975. BMDP2M-Cluster analysis on cases. W. J. Dixon, editor. Health Sciences Computing Facility, U. of Calif., Los Angeles. U. of Calif. Press.

4. Biomedical Computer Programs. 1974. BMD07M-Stepwise discriminant analysis. W. J. Dixon, editor. Health Sciences Computing Facility, U. of Calif., Los Angeles. U. of Calif. Press.

5. Birkeland, P. W. 1974. Pedology, weathering, and geomorphological research. Oxford University Press, New York. 285 p.

6. Buol, S. W., F. D. Hole, and R. J. McCracken. 1973. Soil genesis and classification. Iowa State University Press, Ames. 360 p.

7. Cain, A. J. 1962. The evolution of taxonomic principles. In "Microbial Classification", Twelfth Symposium of the Society for General Microbiology. University Press, Cambridge.

8. Caprio, J. M. 1974. The solar-thermal unit concept in problems related to plant development and potential evapotranspiration. In "Phenology and Seasonality Modeling". Helmut Leith, editor. Springer-Verlag, New York. p. 353-364.

9. Carleton, M. A. 1923. The small grains. Macmillan Co., New York. 699 p.

10. Committee on Tropical Soils. 1972. Soils of the Humid Tropics. National Academy of Sciences, Washington, D. C. 217 p.

11. FAO-UNESCO. 1974. Soil map of the world, Volume I, legend. Paris. 59 p.

12. Foy, C. D., A. L. Fleming, G. R. Burns, and W. H. Armiger. 1967. Characterization of differential aluminum tolerance among varieties of wheat and barley. Soil Sci. Soc. Amer. Proc. 31:513-521.

13. Foy, C. D., W. H. Armiger, L. W. Briggle, and D. A. Reid. 1965. Differential aluminum tolerance of wheat and barley varieties in acid soils. Agron. J. 57:413-417.

14. Gardiner, M. J. 1972. An evaluation of the influence of soil characteristics and climate on crop yields. 2. Influence of temperature. Irish J. of Agr. Res. 11:219-232.

15. Greenland, D. J. 1975. Bringing the Green Revolution to the shifting cultivator. Science 190:841-844.

16. Hough, M. N. 1975. Meteorological models for the effects of weather on barley development and yield. In "Progress in Biometeorology: The Effect of Weather and Climate on Plants". S. W. Thomp (editor-in-chief). Swets and Zeitlinger B. V. Amsterdam. p. 240-251.

17. Hunt, T. F. 1919. The cereals in America. Orange Judd Co., New York. 421 p.

18. Jenny, H. 1941. Factors of soil formation. Macmillan Co., New York. 281 p.

19. Kirby, E. J. M. 1972. The effect of plant density on tiller growth and morphology in barley. J. Agric. Sci. 71:47-52.

20. Kirby, E. J. M. 1969. The effect of sowing date and plant density on barley. Ann. Appl. Biol. 63:513-521.

21. Klages, K. H. M. 1942. Ecological crop geography. Macmillan Co., New York. 615 p.

22. Kubiena, W. L. 1953. The soils of Europe. T. Murby and Co., London. 317 p.

23. Lof, G. O. G., J. A. Duffie and C. O. Smith. 1966. World distribution of solar radiation. Engineering Expt. Station Report No. 21. University of Wisconsin, Madison.

24. Martin, J. H. and W. H. Leonard. 1967. Principles of field crop production. Macmillan Co., New York. 1044 p.

25. McGuire, C. F. and F. H. McNeal. 1974. Quality response of 10 hard red spring wheat cultivars to 25 environments. Crop Sci. 14:175-178.

26. Monthly climatic data for the world: U. S. Dept. of Commerce, National Oceanic and Atmospheric Administration Environmental Data Service, Asheville, North Carolina. Sponsored by the World Meteorological Organization.

27. National Soil Survey Committee of Canada. 1970. The system of soil classification for Canada. Canada Dept. of Agric., Ottawa. 249 p.

28. Nielsen, G. A. (in press, 1976). Use of soils data in land use planning: techniques for displaying soils data to planners and decision makers. In Proceedings of seminar on "Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development in the Tropics". Jan. 18-23. International Crops Research Institute for the Semi-Arid Tropics: Hyderabad, India.

29. Nuttonson, M. Y. 1957. Barley-climate relationships and the use of phenology in ascertaining the thermal and photo-thermal requirements of barley. Amer. Inst. Crop Ecology, Washington, D. C. 388 p.

30. Papadakis, J. 1961. Climatic tables for the world. Buenos Aires, Argentina. 175 p.

31. Smith, G. D. 1973. Soil moisture regimes and their use in soil taxonomies. In "Field Soil Water Regimes". R. R. Bruce, K. W. Flach & H. R. Taylor, editors. Soil Sci. Soc. Amer., Madison, Wsic. p. 1-7.

32. Soil Survey Staff. (in press). Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, USDA Agriculture Handbook No. 436.

33. Soil Survey Staff. 1975. Soil Series of the United States. Soil Conservation Service, USDA.

34. Sokal, R. R. 1974. Classification: purposes, principles, progress, prospects. Science 185:1115-1123.

35. Stace, H. C. T. et. al. 1968. A handbook of Australian soils. Rellin Technical Publications, Glenside, South Australia.

36. Tables of temperature, relative humidity, and precipitation for the world. Great Britain Meteorological Office. London.

37. Thorne, G. N., M. A. Ford, and D. J. Watson. 1968. Growth, development, and yield of spring wheat in artificial climates. Ann. Bot. 32:425-445.

38. Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geogr. Rev. 38:55-94.

39. United States Naval Weather Service worldwide airfield summaries. Volumes I through X. National Technical Information Service, Springfield, Virginia.

40. United States Salinity Lab Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agriculture Handbook No. 60.

41. Unpublished data. Great Plains Barley Nursery. 1953-1973. USDA-ARS, Field Crops Research Branch and State Agr. Expt. Stations, cooperating.

42. Unpublished data. Report on Weatern Cooperative Barley Test. 1957-1974. Conducted by Assoc. Comm. on Plant Breeding of the Natl. Res. Council and Canada Dept. of Agr.

43. Unpublished data. Uniform 2-Row Barley Nursery and Rocky Mountain Barley Nursery. 1965-1973. Compiled by E. A. Hockett. USDA-ARS.

44. Ward, J. H., Jr. and M. E. Hook. 1963. Application of an hierarchical grouping procedure to a problem of grouping profiles. Ed. & Psych. Meas. 23:69-81.

45. Weaver, J. C. 1950. American barley production: a study in agricultural geography. Burgess Publishing Co., Minneapolis. 115 p.

46. Whitehead, A. N. 1925. Science and the modern world. Macmillan, New York. 296 p.

47. Wilsie, C. P. 1962. Crop adaptation and distribution. W. H. Freeman, San Francisco. 448 p.

48. World weather records: U. S. Dept. of Commerce, Environmental Science Services Administration, Environmental Data Service, Washington, D. C.

49. Wortman, S. 1975. World food needs and opportunities: the overview. In "All-Out Food Production: Strategy and Resource Implications". Amer. Soc. Agron. Special Publ. No. 23. p. 1-14.