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

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.

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Date 5-27-76

CLUSTER ANALYSIS OF BARLEY BREEDING

CENTERS USING ENVIRONMENTAL VARIABLES

by

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A thesis submitted in partial fulfillment
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MASTER OF SCIENCE

in

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ABSTRACT

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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. Monitoring 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 $30^{o}F$ ($-1.1^{o}C$) winter isotherm on the south, and the $70^{o}F$ ($21.1^{o}C$) isotherm on the north, is climatically unsuited to the growing of either winter or spring barley (45). Just as the $70^{o}F$ ($21.1^{o}C$) 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°F (15° to 20.6°C) with normal sowing, tillering begins at about 56° to 58°F (13.3° to 14.4°C), and ceases when temperatures drop to 36° to 37°F (2.2° to 2.8°C) (29). When sowing is late, the seedlings may emerge at temperatures of 43°F (6.1°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 represent 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).

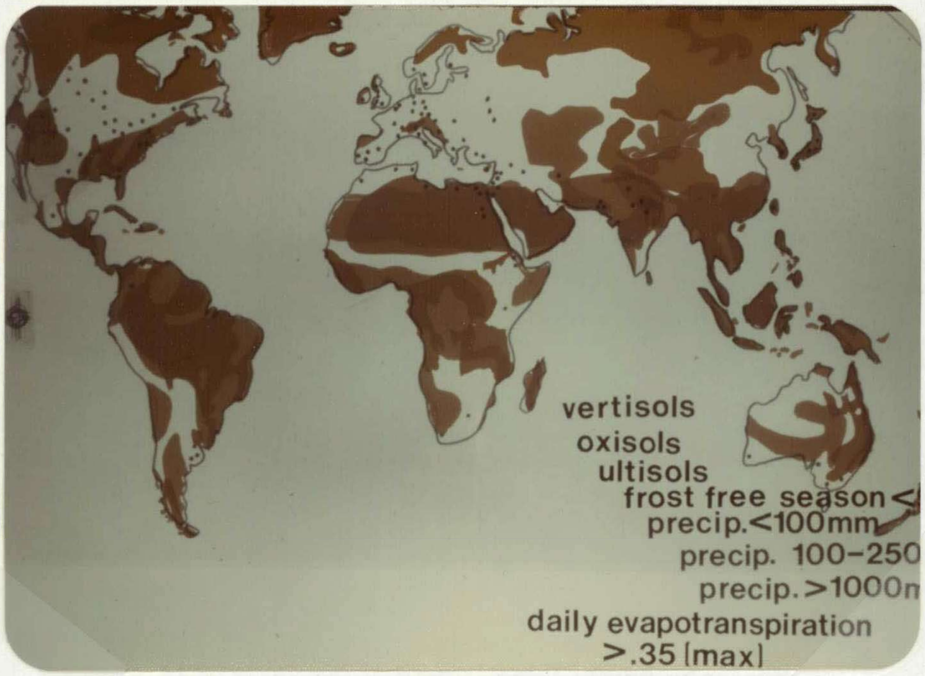

Figure 1: COMPOSITE OVERLAY MAP SHOWING ENVIRONMENTAL CONSTRAINTS TO DRYLAND BARLEY PRODUCTION

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 p^{th} root of the sums or the p^{th} 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.

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