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In order to meet future food demands, production in the developing nations of the world must be increased. This will require that present and new technologies be transferred to the developing nations as rapidly as possible, so that these technologies may be translated into farming systems which are economically attractive and socially acceptable to farmers in these countries.

This present paper addresses the topic of a systematic identification of major agricultural climatic zones in the world. The idea is to select locations throughout the world with significant variations, yet also provide some common factors in such a manner as to permit the determination of major climatic influences on crop growth. These sites would then be identified as reference climates. As will be demonstrated, a surprisingly small number of such strategically located sites can provide the basis for crop-production-technology transfer, if the appropriate crop varieties are grown at all of the sites, and the proper sets of soils and weather data are simultaneously collected.

The greatest plant-growth research-data void exists at the present is in the extensive area of plant-environment interactions. This paper identifies part of a rationale for eliminating the void with a minimum of expenditure and in a relatively short time. Such organization of research effort must take place if the world's food needs are to be met in the coming year.

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REFERENCE CLIMATE SITES FOR AGRICULTURAL TECHNOLOGY TRANSFER

By

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Reference Climate Sites for Agricultural Technology Transfer[1]

R.H. Shaw[2] and R. W. Hill[3]

Introduction

In order to meet future food demands, production in the developing nations of the world must be increased. This will require that present and new technologies be transferred to the developing nations as rapidly as possible, so that these technologies may be translated into farming systems which are economically attractive and socially acceptable to farmers in these countries.

Many variety testing trials are conducted around the world. For example, in 1973 standardized soybean variety evaluation experiments were tested in several countries as part of a research program being carried out for the Agency for International Development (AID). These trials were organized to determine if soybeans will grow in different areas of the world, what varieties and types are best adapted, and what is the potential of soybeans in different environments. Extensive testing is now being done by the International Soybean Program (INTSOY) and 59 countries were cooperating in 1974. Figure 1 (Whigham, 1974) shows the location of these sites.

Most of the yield trials now being conducted generate large amounts of site-specific data. There is a divergence of opinion as to how much transferability of these data can be accomplished. In the Herbert Kendall Hayes Memorial Lecture at the University of Minnesota in 1974, Sterling Wortman stated:

> "It has also been realized by national and international authorities -- but only in the last several years -- that the biological components of agricultural technology (varieties, disease and insect control measures, soil management practices, fertilizer usage) are not generally transferable among farming regions and certainly not from temperate climate to tropical areas. Production systems must be devised for every crop, for every season, for every nation -- and that is a big and complex task."

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Those of us involved in the project "Agricultural Technology Transfer" obviously have a different opinion. We believe that if sufficient details are collected on weather, soils, and crop data, and if proper biological and physical models are developed, transfer of most of the biological components of agricultural technology can be made. We believe that because of the present world food crisis, because of the necessity for rapidly increasing world food production, and because of the large expenditures of time and money required to conduct the numerous yield trials throughout the world, data transferability is an essential research project. It will be necessary to mesh together the component parts (climate, soils, variety, pests, fertility and husbandry) of crop-production technology to bring about an effective transfer.

In this project system analysis techniques will be used in order to develop appropriate mathematical relationships describing significant interactions among the components of crop production. These relationships will be synthesized into computer simulation models of the various crops, tested with field data, then utilized as an aid in technology transfer. In the process significant contributions will be made in directing continuing agricultural research programs as well as organizing available data into a more retrievable format.

This present paper addresses the topic of a systematic identification of major agricultural climatic zones in the world. The idea is to select locations throughout the world with significant variations, yet also provide some common factors in such a manner as to permit the determination of major climatic influences on crop growth. These sites would then be identified as reference climates. As will be demonstrated, a surprisingly small number of such strategically located sites can provide the basis for crop-production-technology transfer, if the appropriate crop varieties are grown at all of the sites, and the proper sets of soils and weather data are simultaneously collected.

The greatest plant-growth research-data void which exists at the present is in the extensive area of plant-environment interactions. This paper identifies part of a rationale for eliminating the void with a minimum of expenditure and in a relatively short time. Such organization of research effort must take place if the world's food needs are to be met in the coming year.

World Climates

The effects of daily weather parameters (temperature, precipitation, sunshine, etc.) over a period of several years add up to the climate which exists at a given site. A climate classification system has been used to identify the reference sites. At these sites, daily weather data will be collected as described later.

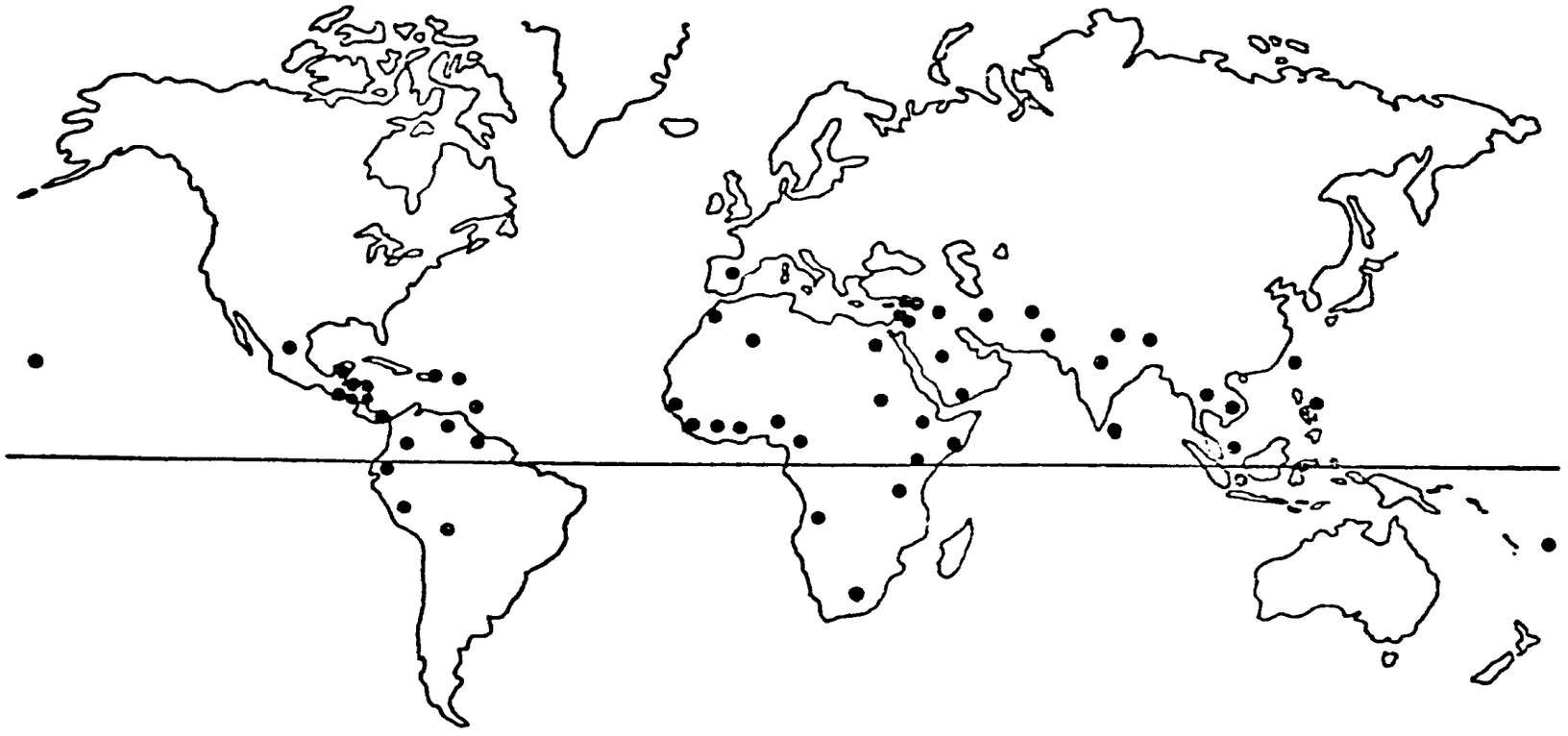

Figure 1. INTSOY soybean test plot locations. (After Whigham, 1974)

Analysis will be made to obtain a statistical representation of any previous weather data available at these sites. Such a representation will permit some limited transfer of weather effects to similar major climate areas which are devoid of measured data. This will be in a standardized form for improved retrievability and application. At the reference sites, the full set of daily weather data (as described later) will be collected as part of this project.

Climate Classification

Many systems have been used to develop different world climatic classifications, and many have considerable merit. There seemed to be no "best" classification system to use for this study. Trewartha's climatic classification (Trewartha, 1968) is a modification of Köppen, probably the best known system in the world. The modifications made seem to make it fit certain agricultural areas in the U.S. better than Köppen's classification, and it was selected primarily for that reason.

Under this classification system, there are six major climatic types. Five are separated on the basis of temperature. The critical temperatures used are: mean monthly temperatures of 65° F (18° C) and 50° F (10° C). A mean monthly temperature of 65° F or greater is usually considered as designating a frost-free area. An average monthly temperature of 50° F is considered as representing the lower temperature limit for plant growth. One month only with a temperature of 50°, or greater, is believed to coincide approximately with the poleward limit of forests in continental locations. A period of 4 months with 50° or more is commonly used as a boundary separating cool from warm climates. Climates having fewer than 4 months with average temperatures of 50° have been considered as having limited agricultural potential, although developments in agriculture in relatively recent years have remarkedly increased short-season grain production in these climates.

Major Climatic Groups

1) Tropical humid climates (A). Frost limits occur in continental locations while in marine areas 65° F (18° C) is the lower temperature limit for the coolest month. If frost data are not available, it must have all months with a mean temperature of 65° F (18° C) or greater. Further subdivisions include three types of precipitation distribution: A_r - (rainy) 10 to 12 months wet, 0-2 months dry; A_w - winter dry, more than 2 months dry; and A_s - summer dry, more than 2 months dry. A drymmonth is defined as a month receiving 1/12 or less of the value obtained from Eq. (1) given later.

2) Subtropical climates (C). 8-12 months 50° F (10° C) or above, coolest month below 65° F (18° C). Further subdivisions include: C_a - hot summer, warmest month over 72° F (22.2° C); C_b - cool summer, warmest month below 72° F (22.2° C); C_f - no dry season, driest summer month > 1.2" (3 cm); C_s - summer dry, at least 3

times as much rain in winter half year as in summer half year; and C_w - winter dry, at least 10 times as much rain in summer half year as in winter half year. Both temperature and precipitation designators are used to define the climate zone.

3) Temperate climates (D). 4-9 months 50° F (10°C) or above. Subdivisions include: D_o - oceanic, cold month over 32° F (0° C); D_c - continental, cold month under 32° F (0° C). a, b, f, s, w are defined as for C climates.

4) Boreal climates (E). 1-3 months 50° F (10° C) or above.

5) Polar climate (F). No month 50° F (10° C) or above. Subdivided on basis of warmest month temperature.

In Trewartha's classification, one type is separated out on the basis of the water balance. This type occurs where evaporation exceeds precipitation and is called a B climate. The boundary is determined by:

$$R = 1/2\ T - 1/4\ PW \qquad (1)$$

where R = annual rainfall in inches; T = annual mean temperature, °F and PW is the % annual rainfall in the winter half-year. Areas with rainfall less than R are considered B climates. This is further divided into two groups, steppe and desert, by halving the value obtained from Equation 1 with a desert climate having precipitation below this value. Since the proposed project includes irrigation, this classification would not be directly used, thus all climates would be subdivided on the basis of the first five groups. However, Equation 1 could be used to obtain some measure of the water deficit for the area. Water balance equations, which account for plant growth stage and time variation of rainfall, will be an integral part of the final computer program.

A map of the world climates, as defined by Trewartha, is shown in Fig. 2. The heavy dashed line shows the boundary zone between the different climates, excluding the B, or dry, classification. It should quickly become evident after viewing this map, that the so-called developed areas of the world are mostly in the C and D climates with some areas having considerable areas of E climates. Much of the agricultural technology in the world has been developed in these areas. In North America, these are the so-called Cotton (C climate), Corn (D climate), and Wheat (C, D, and E temperature type, but B_s precipitation type climate) Belts. In these regions, large masses of data are available, but unfortunately, not all types of data proposed for this project have been generally simultaneously collected. The developing areas of the world are largely in areas of A and B climates. When classified by temperature instead of the water balance, the B areas are largely A and C climates. These areas are recognized as having tremendous problems in increasing agricultural production because of climate, soil, insect, disease, and other problems.

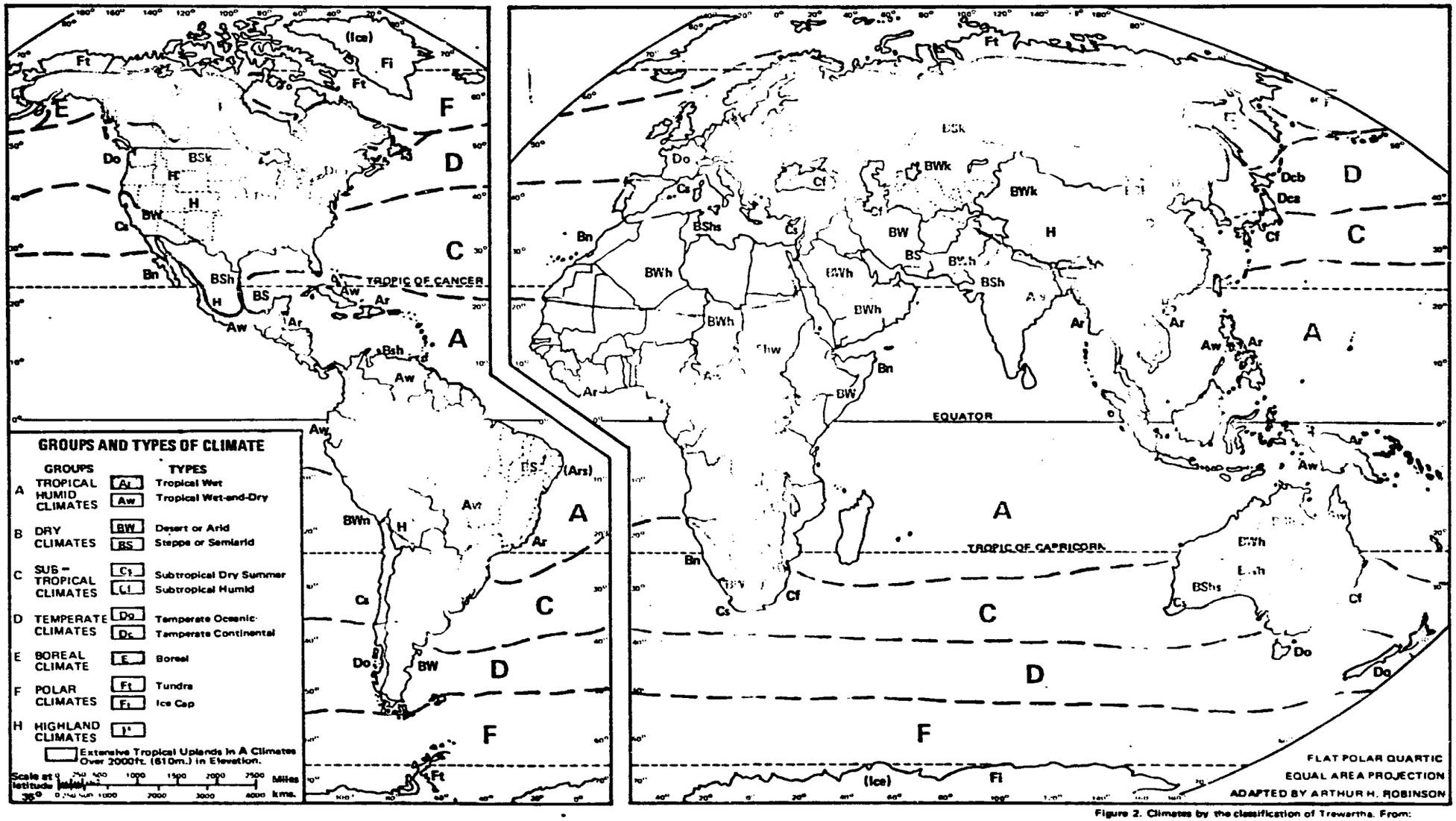

Figure 2. Climates by the classification of Trewartha. From: An Introduction to Climate, by Trewartha, 1968. Copyright McGraw-Hill Book Co., N.Y., 1967. Used with permission of McGraw-Hill Book Company.

Weather Data to be Measured

The basis for the project are: to develop a procedure which will allow as much data (and information) transfer from the developed areas to the developing areas as is possible, and to generate new data in a systematic fashion in the developing areas (the A and B climates). At the reference sites, daily weather data will be collected at the same time as indicator crop varieties are grown. Maximum and minimum air temperatures, precipitation, solar radiation, percent possible sunshine, pan evaporation, wind, humidity, and perhaps dewpoint, are weather parameters which represent a reasonable data set for each site.

Different crop species, and even varieties within a species, may interact differently with the same environment. To determine what these interactions may be, it is necessary that we record detailed plant, soil, and weather data. The weather data needed are observations which will either directly describe the plant's response to the climate, or be used in a model or equation to evaluate the climatic effects.

Temperature affects the plant or plant processes in several ways (growth, photosynthesis, evaporation). For growth and development rate of the plant a daily value is needed. This daily value is adequately described by the maximum and minimum temperatues. These observations can be used to measure critical temperatures or as inputs to growing degree unit (heat unit) calculations. (Aspiazu and Shaw, 1972. Gilmore and Rogers, 1958; Mederski, et. al. 1973)

Solar radiation provides the energy for photosynthesis and evaporation. If solar radiation measurements are not available, duration or percent of possible sunshine measurements can be used as a substitute. Daily totals of these factors would be necessary and would be used as inputs into several stages of the computer program.

Class A, evaporation-pan data would be obtained on a daily basis. This is the standard for evaporation proposed by the World Meteorological Organization and provides an estimate of the potential evaporation for each day. By using proper conversion factors it can be converted to the potential evapotranspiration for different stages of development for different crop covers.

Rainfall totals would be measured on a daily basis.

Day length is a factor which can be calculated for each location. It could well be the factor which creates the greatest problems in transferring data. The annual ranges of day lengths by 10° of latitude are summarized in Table 1.

Table 1. Daylength by 10° latitude increments.

Latitude	Longest Day	Shortest Day
0°	12 hrs 0 min	12 hrs 0 min
10°	12 hrs 35 min	11 hrs 25 min
20°	13 hrs 12 min	10 hrs 48 min
30°	13 hrs 56 min	10 hrs 4 min
40°	14 hrs 52 min	9 hrs 9 min
50°	16 hrs 18 min	7 hrs 42 min
60°	18 hrs 27 min	5 hrs 33 min
70°	24 hrs	0 hrs
80°	24 hrs	0 hrs
90°	24 hrs	0 hrs

At the time of the vernal and autumnal equinoxes (March 21 and September 23) all latitudes have 12 hours day length. Some plant species are very day length sensitive, other quite insensitive. Plant breeders are moving in the direction of reducing the day length sensitivity factor, which will make the problem of data transferability much simpler.

Humidity and wind have both been related to crop production, but for the data transferability project are not as essential as the other observations. Humidity is related to the evaporative demand. It is one of several factors integrated into the open-pan evaporation value. Humidity is often used as a measure of the dryness of the air or indirectly as a water availability parameter. The proposed moisture-balance calculations will provide information on this. Wind may cause significant physical crop damage under extreme conditions, but for most situations becomes a component of the water demand, which is estimated by the open-pan evaporation. Measurement of wind and humidity is considered desirable, but not absolutely necessary; however, if an equation such as the Penman combination potential evapotranspiration equation is used then daily mean dewpoint temperature and wind data would be required.

The proposed observations are believed to provide all the necessary weather inputs to the program and with proper physical and biological models should evaluate the climate and weather effects.

Location of Reference Climatic Sites

The agricultural technology transfer strategy requires sets of crop growth data obtained at sites which represent a wide range of climatic

conditions. In order to provide this range of conditions, a set of reference climatic sites needs to be established which would include the climatic types previously discussed, which should be existing sites having adequate climatological records. Locations should be selected so that within each day length period, a range of temperature and precipitation conditions are found.

The highest level of development of agriculture is generally in the C and D climates. Theoretically, technology used in C and D climates can transfer into similar C and D climates of the world with little or no modifications. Transfer of C and D technology to areas with other climatic types could require considerable modification for successful adaptation. Thus, the use of climate classification can pinpoint potential modification programs required in developing countries of the world where extensive areas are not C and D climates.

The desired characteristics of typical reference stations are discussed in the following material:

A_r climates: Tropical rainy

In the low latitude sites with constant day length, it would be desirable to have a station which represents the almost continually wet area with relatively constant temperatures throughout the year. Manaus, Brazil, (Table 2) would be a typical A_r station. This station would represent the Amazon Basin Area, which is programmed for agricultural development. Uaupes, Brazil, has similar temperatures but is more wet. Other A_r areas are in equatorial Africa and southeast Asia, all areas being located near the equator.

A_w climates: Tropical wet and dry

A_w climates are present in extensive areas in the tropics between latitudes 5° and 20°. A low latitude site which represents the wet-dry tropical area with relatively constant daylength and somewhat more variable temperatures throughout the year would represent significant areas in the developing nations. Santa Isabel, Puerto Rico, represents a relatively dry A_w climate. Lajas, Puerto Rico, where an Experiment Station is located, is a wetter A_w climate which almost types as an A_r climate because of the relatively uniform rainfall pattern. San Andrés, El Salvador, has a very rainy wet season and a very dry, dry season. These stations show the wide range of rainfall conditions which are included in A_w climates.

C_{bf} low latitude, high elevation climate

This climate represents areas with relatively uniform day length. An example is Cuenca, Ecuador, where the cooler months are the drier months with temperatures cooler than normal because of altitude effects. They do not represent significant agricultural areas of the world but

Table 2. Climatic data for selected stations, temperature in °F, precipitation in inches.[1]

Climate Factor	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
						Month							
1 - Tropical Rainy A_r													
Manaus, Brazil 03 08S 60 01W 144 ft													
Temp	80.6	80.2	78.3	80.2	79.7	80.1	80.2	81.7	82.6	81.9	80.8	79.9	80.5
Precip	10.94	10.94	11.81	11.30	7.60	3.90	2.40	1.61	2.44	4.41	6.50	8.66	82.51
Aaupes, Brazil 00 08S 67 05W 278 ft													
Temp	77.7	77.9	78.1	77.5	77.0	76.1	75.6	76.6	77.7	78.1	78.4	77.9	77.4
Precip	11.10	9.96	11.22	10.51	12.48	9.84	9.53	7.68	5.83	6.81	7.95	12.01	114.92
2 - Tropical Wet and Dry (A_w)													
Santa Isabel, Puerto Rico 18 00N 66 26W 28 ft													
Temp	No Temp												
Precip	0.85	0.98	0.48	1.72	4.21	3.91	2.60	4.23	5.96	5.22	3.29	1.38	34.74
Lajas, Puerto Rico 18 02N 67 05W 327 ft													
Temp	73.4	73.4	74.3	76.5	78.4	79.7	79.7	79.3	79.0	78.1	76.6	74.5	76.9
Precip	2.33	1.34	1.72	3.83	3.66	2.80	3.91	6.09	7.70	6.11	4.35	3.24	47.08
San Andres, El Salvador 13 49N 89 24W 1525 ft													
Temp	75.2	75.4	76.5	77.5	78.1	76.6	77.7	76.6	77.0	75.9	75.2	75.0	76.4
Precip	0.43	0.08	0.16	2.13	7.17	11.10	13.74	10.83	12.13	7.24	1.57	0.08	66.7

Table 2. Continued

Climate Factor	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
						Month							
3 - Low Latitude, High Elevation (C_{bf})													
Cuenca, Ecuador 02 53S 78 39W 8304 ft													
Temp	58.3	58.6	58.5	58.1	57.4	56.1	55.4	55.8	57.0	57.7	57.4	58.5	57.4
Precip	2.60	2.32	3.66	4.96	3.62	1.81	0.83	1.06	1.57	3.31	2.20	2.91	30.9
Palmira (Agric. Exp. Sta.), Columbia 03 31N 76 19W 3290 ft (Not a C_{bf} climate)													
Temp	75.2	75.6	76.1	75.4	75.0	74.5	75.2	75.2	75.9	74.5	74.5	74.8	75.2
Precip	2.71	2.61	3.17	6.63	6.38	2.85	1.43	0.86	2.03	6.42	4.60	3.47	43.16
4 - Steppe Climate, Relatively Low Latitude													
Brownsville, Texas 25 54N 97 26W 33 ft (Temp data) C_aB_s)													
Weslaco, Texas 26 09N 97 58W 75 ft (Precip data)													
Temp	61.3	64.0	67.8	73.9	79.0	82.8	84.0	84.0	81.1	75.9	67.6	63.0	73.7
Precip	1.66	1.03	1.07	1.53	2.70	2.46	1.71	2.67	4.13	2.10	1.02	1.26	23.34
Mexico City 19 26N 99 08W 7555 ft (C_bB_s)													
Temp	54.1	57.0	60.8	63.9	64.9	63.7	62.1	62.1	62.1	59.0	56.7	54.3	59.9
Precip	0.21	0.24	0.34	0.51	2.03	4.10	4.93	4.07	4.61	1.36	0.54	0.64	23.2
5 - Humid Subtropical (C_{af})													
Stoneville, Mississippi 33 25N 90 55W 127 ft.													
Temp	46.7	48.9	55.9	64.0	71.6	79.5	81.6	81.3	75.6	65.3	53.6	47.4	64.3
Precip	5.77	4.84	5.71	4.74	3.96	3.61	3.96	2.51	2.41	2.47	4.13	5.56	49.7

Table 2. Continued

Climate Factor	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
						Month							
6 - Subhumid Temperate, Hot Summer (D_{caf})													
Ames, Iowa 42 00N 93 39W 1004 ft													
Temp	19.5	23.0	35.3	49.1	60.2	69.7	74.4	72.5	64.2	52.5	36.7	24.4	48.5
Precip	0.93	0.94	1.57	2.78	4.26	4.58	3.57	3.67	3.73	2.33	1.41	1.01	30.8
7 - Dry Temperate (D_{cb}, B_s)													
Ft. Collins, Colorado 40 35N 105 05W 5025 ft													
Temp	26.3	28.8	35.9	45.7	54.6	63.9	69.5	68.2	59.8	48.6	36.4	28.4	47.2
Precip	0.41	0.56	1.00	1.98	2.85	1.65	1.54	1.39	1.23	1.12	0.50	0.45	14.7
8 - Subhumid Temperate, Cool Summer													
Crookston, Minnesota 47 48N 96 36W 888 ft.													
Temp	4.1	7.9	22.6	41.4	54.3	64.1	69.5	66.9	57.8	44.9	26.6	12.1	39.4
Precip	0.57	0.60	0.87	1.59	2.69	3.55	3.11	2.96	2.02	1.42	0.81	0.60	20.8

[1]Data presented were taken from U.S.D.C., 1965, World Weather Records, 1951-60 and Wernstedt, Frederick L., 1972, World Climatic Data.

would provide valuable data on the temperature-day length interaction on plant development. These areas are small enough that they are not shown on Figure 2. If locations cannot be found as elevations high enough to type as "c" climates, locations such as Palmera, Columbia, could be used. Its rather low elevation (3290 ft.) does not provide cool enough temperatures for a C climate, and it types as a borderline A_r - A_w climate. Calli, Columbia, is located very close to Palmira and would also represent a similar type climate. Low latitude, high-elevation climates are also located in eastern Africa and Indonesia.

$C_a(B_s)$: Subtropical climates with low rainfall

A subtropical climate with low rainfall represents large problem areas in the world. Such climates are found in Mexico, Argentina, Australia, South Africa, North Africa, and an area from Inda-Pakistan to the Mediterranean Sea. Where not irrigated, dry years may severely limit agricultural production. Although the temperatures of many of these areas may not be too much different from wetter areas, they should be included because they represent large areas now being irrigated with potential for much larger areas of irrigation. A few of these areas may type as A climates, but most will be of the C type. A range of temperature conditions is available: data for Brownsville-Weslaco, Texas, represents a typical location, and Mexico City (Chapingo) represents a higher altitude station with a cool summer. Another extreme could be locations like Jodhpur, India, which has four months averaging warmer than 86° F (30° C), with the hottest month averaging 94.1° F (34.5° C).

C_{af}: Humid subtropical climate

A typical Cotton Belt climate would be that of Stoneville, Mississippi. It has no distinctly dry period and has warm summers. It will provide part of the continum of day length which is desired. Other major C_{af} climate regions are located in South America and China, with small areas in Africa, Australia, Japan, and the eastern Mediteranean areas.

D_{caf}: Subhumid, temperate climate, hot summer

Ames, Iowa, is a temperate climate with a cold winter and a hot summer and is a typical Corn Belt climate. Stations selected further east in the Corn Belt would have similar warm season precipitation but heavier cold season precipitation. Other areas with D_{ca} climate are in the southeast Europe, China, and Japan.

$D_{cb}(B_s)$: Dry, temperate climate, cool summer

Fort Collins, Colorado, is a B_s climate by Trewartha's system. Since we are considering irrigation, it would be a D_{cb} climate with the same day length features as Ames but with cooler summer temperatures, primarily because of the elevation of Fort Collins.

D_{cb} (not B_s): Subhumid, temperate climate, cool summer

This climate has a cold winter and a cool summer, but differs from that typified by Fort Collins with a cooler temperature caused by an increase in the latitude, not elevation. The latitude change also introduces a day length change. A typical location for this climate is Croohatan, Minnesota. This climate is present in the northern part of the eastern 2/3 of the U.S., in eastern Europe, western USSR, China, and Japan.

A minimum of eight stations have been selected to provide a range of temperature, day length, and precipitation factors which would provide and adequate range of climatic conditions for an information transfer project. These eight would be 1) tropical rainy; 2) tropical wet and dry; 3) low latitude, high elevation; 4) steppe, dry, relatively low latitude; 5) humid subtropical; 6) subhumid, temperature, hot summer; 7) dry, temperatue, cool summer; and 8) subhumid, temperate, cool summer. However, it would be desirable to have more than one station in each climate so that the range within each type can be represented.

Application

The concepts presented in this paper suggest that agricultural production technology in temperate climates (C and D), notably in the U.S., could be transferred rather directly to other C and D climates of the world. The climates and soils of a number of developing areas are near duplicates of developed areas. Thus information regarding plant, soil, and climate interactions may be immediately transferred. In these zones the main limitations of successful adaptations would not be climate and soils. Adjustments may be necessary to suitably account for new socio-economic constraints, such as the availability and expertise of the labor pool, or resource constraints such as amount of water available for irrigation. However, it should be possible to estimate directly the yield performance of crop varieties under potential husbandry regimes. Such transfer is not now possible because past and present agricultural research has been oriented toward site specific programs without collection of sufficient climate-crop data sets for transfer.

Technology transfer from C and D climates into non C and D zones of the world presents more difficulty, as is readily apparent. The application of climate classification can help identify needed modifications in research programs for increased effectiveness towards adaptive transfer. Data collected at reference climate sites will aid in determining the climate interactions with crop variety and management regions. Once these interactions are known and understood, performance information can be transferred even to an area of dissimilar climates, aided by the classification of this climate. If more detailed data on the local climate is available beyond what is known for the climate classification, the information transfer can be accomplished with improved accuracy and validity.

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