Reading 4
Crops & Climates

Crop geography deals with all of the factors related to the distribution and cultivation of crop plants. In addition to the physical and biotic environment, it must also be concerned with the social, economic, political, technological, and historical forces that shape cropping practices over the entire world. By its very nature crop geography must treat large areas and long periods of time. Even though crop geography deals solely with crop plants, its scope is broad because of the interplay of social customs and historical events with crops and cropping patterns.

Crop ecology is concerned with the relations between crop plants and their physical and biological environments, frequently with no regard for economics. Its scope ranges from continental land areas to the immediate environment of a single stoma. It deals with the same environmental factors and relations that concern plant ecology, but the focus is on crops. Today, the differences between plant ecology and crop ecology have become small, because many of the exclusive domains of the traditional plant ecologists–virgin forests, tundra, and deserts–are being critically examined to determine whether they will serve a productive function in our economic structure. It seems probable that in the future there will be little or no distinction between plant ecology and crop ecology, because even the trees of wilderness areas and the plankton of oceans will be considered as crops to be manipulated for production.

Several examples of the complex interplay of factors involved in crop geography are in order. Historical forces have a great effect. During and shortly after the American Civil War (1861–1865) millions of acres of cropland in the southeastern United States were abandoned because of a labor shortage. A high proportion of these fields were naturally seeded by pines, which reached a peak of sawlog merchantability in the period 1920–1940. Cotton never entirely recovered its place in the regional economy in the period after the war, and as a result the agricultural base of the region changed from cotton to forest products. Tobacco production, however, did not shift because tobacco has an exceptionally high value per acre, and because the soils of the region are favorable for certain types of tobacco highly valued for the manufacture of cigarettes.

Cultural factors and personal preference also play a role in the choice of crops. Wheat recently shipped to a nation in the throes of a famine was rejected by all but the starving because they preferred rice. Even if the climate and soils of such a country were well adapted to wheat production, several generations would be required for its people to develop a taste for wheat.

Technological forces are also important. In the tropics a form of agriculture is practiced in which all merchantable trees in an area are cut and removed and those remaining are felled and burned, the soil being enriched by the ashes. Several successive crops, such as hill rice, are grown on the land, until it becomes too unproductive to justify further cultivation. It is then either allowed to revert to forest or is planted to a desirable timber species such as teak (*Tectona grandis*). The repetition of this process over many years has resulted in vast changes in the vegetative cover of the landscape. This pattern of shifting agriculture is considered by some to be one of the major agricultural problems of the tropics.

CLIMATE

Since climate is the principal factor that controls crop distribution, an examination of the major climates of the world will reveal the patterns that help establish the distribution of crops. In order to interpret descriptive data, it is first necessary to understand how daily weather data are compiled.

Temperature

Temperature, the simplest weather element to measure, is probably more frequently used than any other kind of data. Temperature and precipitation records are often the only ones that have been collected at many stations throughout the world, which limits the number of ways weather data can be universally expressed.

The **absolute maximum** and **absolute minimum temperatures** are the highest and lowest temperatures reached, if even for only a second, in the course of a year. They are usually accompanied by date and sometimes by duration.

The **yearly mean temperature** is the arithmetic average of the daily mean temperatures (an average of the daily maxima and the minima) over the course of a year. Mean temperatures of winter months are sometimes contrasted with mean temperatures of summer months for climatic comparisons.

The **mean maximum** and **mean minimum temperatures** are averages of the daily maxima and minima over a given period of time.

Deviation from normal is used, as it is with reference to precipitation, to express deviation from the average of the mean temperatures on any particular date. The United States National Weather Service regularly announces this information, deriving it from a “normalized” curve based on averages for a number of years.

In a limited number of locations **soil temperatures** are recorded. However, these data are frequently collected for ecological studies in locations under sods or common field grasses that may be far removed from crop fields.

Precipitation

The amount of precipitation is expressed in many ways, but perhaps most often as **average annual precipitation** (Fig. 1). There is a limit, however, to the time period to which an average value may

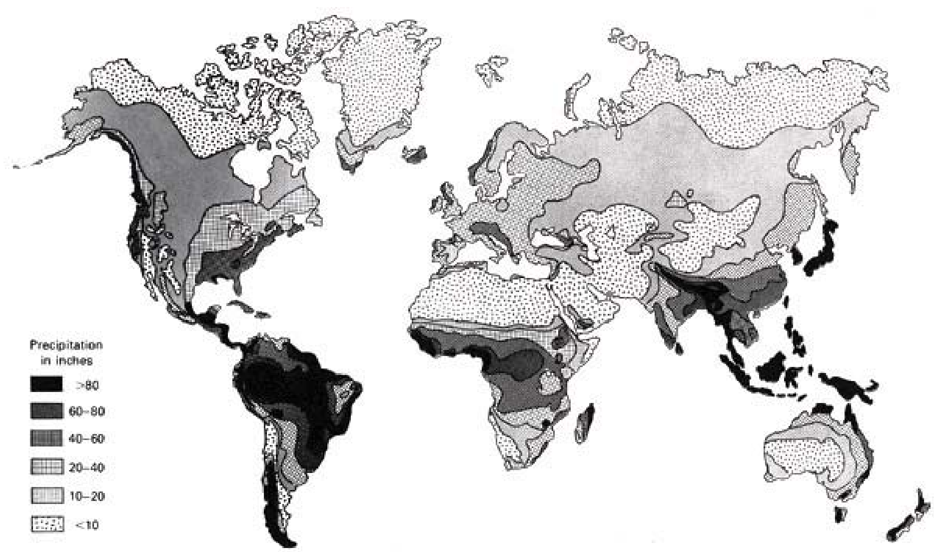


Fig. 1. Average annual precipitation in the world.
[From A Graphic Summary of World Agriculture (USDA Miscellaneous Publication 705), 1964.]

reasonably be applied. Even though data for several hundreds of years are available at some stations in England, the entire period is not used because over this much time a true climatic change may have occurred. Therefore, in order for an average value to be meaningful under today's climatic regime, it should be derived from data accumulated during the past 25 to 35 years. **Mean winter precipitation** and **mean summer precipitation** are frequently used when describing the climate of a region. When precipitation is in the form of snow, the total depth of snow is given along with a factor that can be used to convert the snow to inches of water. A 1:10 ratio of water to snow is sometimes used when actual conversion data are not available.

Growing-season rainfall is an expression frequently used for agricultural purposes, but because the growing season is not the same length at all latitudes, such data are not always directly comparable. The growing season is considered to be the average length of the period between the last spring frost and the first fall frost, the **frost-free season**.

Graphic techniques, showing **average monthly precipitation**, are useful for making rapid surveys. The **total monthly precipitation** is sometimes used as a general index of drought conditions, especially during summer months. When it falls below the necessary minimum determined for a particular area, drought conditions are considered to prevail.

The **deviation from normal precipitation** is an expression frequently used by weather reporters. This value (and its equivalent for temperature) may be useful when studying growth performance of native plants. **Normal precipitation** is defined as the average precipitation for any particular period.

Humidity

Atmospheric moisture may be described in a number of ways. **Relative humidity**, the most frequently used unit of measure, is the actual quantity of water vapor in the atmosphere expressed as a percentage of the maximum amount that the air is capable of holding at a given temperature. The amount of water vapor that the atmosphere can hold increases with temperature. Thus the **drying power** of air, which is proportional to the water-vapor deficit below saturation, is related to relative humidity and temperature. At high temperatures small differences in the relative humidity represent large differences in drying power; at low temperatures, differences in relative humidity represent smaller differences in drying power. **Absolute humidity** is the mass of water vapor per unit volume of air, usually expressed as grams of water per cubic meter of air. **Specific humidity** is the weight of the water vapor per unit weight of air (including the weight of the water vapor). Thus absolute humidity is a function of volume, and specific humidity is a function of weight.

Light

Unfortunately, the amount of light is not generally expressed directly in weather data. Even actual sunshine data are not generally available, and so **potential sunlight** (sunrise to sunset) obtained from tables calculated for different latitudes is generally used. Such tables do not provide a good quantitative estimate of light because of the variable nature of clouds and fog. The total hours of sunshine each day can be recorded by an instrument called a Stokes-Campbell sunshine duration recorder, which concentrates the sun's rays and burns a line in a strip of paper.

The length of the daily photoperiod varies greatly at different latitudes. Natural vegetation has responded to latitudinal variations by adapting to photoperiod. Thus many plants cannot be successfully moved from one latitude to another even though other environmental factors are compatible.

THE THORNTHWAITE CLASSIFICATION OF CLIMATES

The classification of climates proposed by C.W. Tbornthwaite resembles Köppen's insofar as combinations of letters are used to designate individual climates and plant response is used to integrate the climatic elements. Three factors enter into Thornthwaite's description of climatic types–precipitation effectiveness, seasonal distribution of precipitation, and temperature efficiency.

Precipitation effectiveness is represented by a P-E ratio, in which monthly precipitation is divided by monthly evaporation. The P-E index is the summation of monthly P-E ratios. There are 5 humidity provinces (designated by capital letters), each associated with a particular vegetation type:

Letter	Humidity province	Vegetation	P-E index
A	Wet	Rainforest	> 127
B	Humid	Forest	64–127
C	Subhumid	Grassland	32–63
D	Semiarid	Steppe	16–31
E	Arid	Desert	< 16

The humidity provinces are subdivided into subtypes (designated by lower case letters) on the basis of seasonal distribution:

Letter	Distribution of precipitation
r	Abundant in all seasons
s	Sparse in summer
w	Sparse in winter
d	Sparse in all seasons

The **temperature efficiency** (T-F) index is obtained by summing the monthly mean Fahrenheit temperatures, subtracting 32°F, and dividing by 4. There are 6 temperature provinces, each designated by a capital letter marked with a prime:

Letter	Temperature province	T-E index
A'	Tropical	> 128
B'	Mesothermal	64–128
C'	Microthermal	32–64
D'	Taiga	16–32
E'	Tundra	0–16
F'	Perpetual frost	< 0

Of the 120 possible combinations, only 32 are recognized as actual climatic types. Figure 2 illustrates the relations between P-E and T-E indices and the natural vegetation. The world distribution of climates according to the Thornthwaite classification is shown in Fig. 3.

CROP GEOGRAPHY

The distribution of natural vegetation depends on (1) environment, (2) plant response, (3) plant migrations, and (4) the evolution of floras and climax vegetation. These all have somewhat differ-

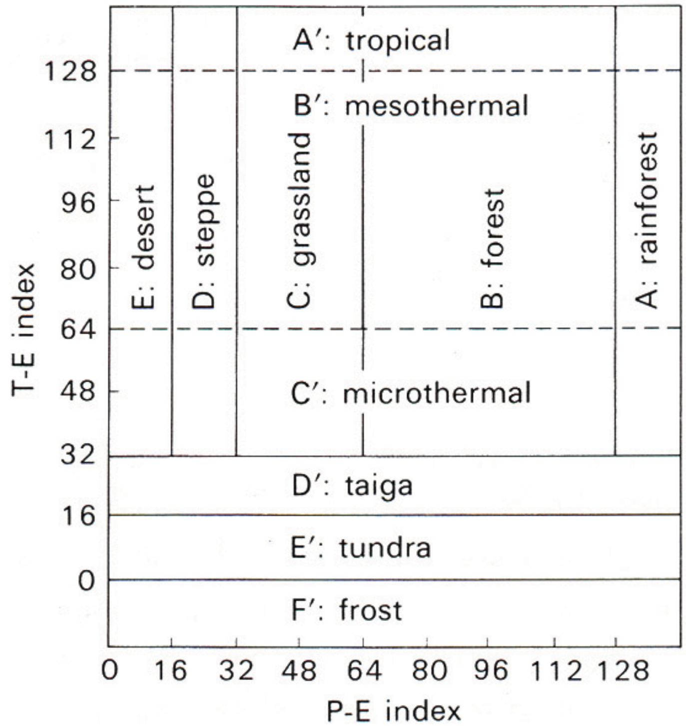
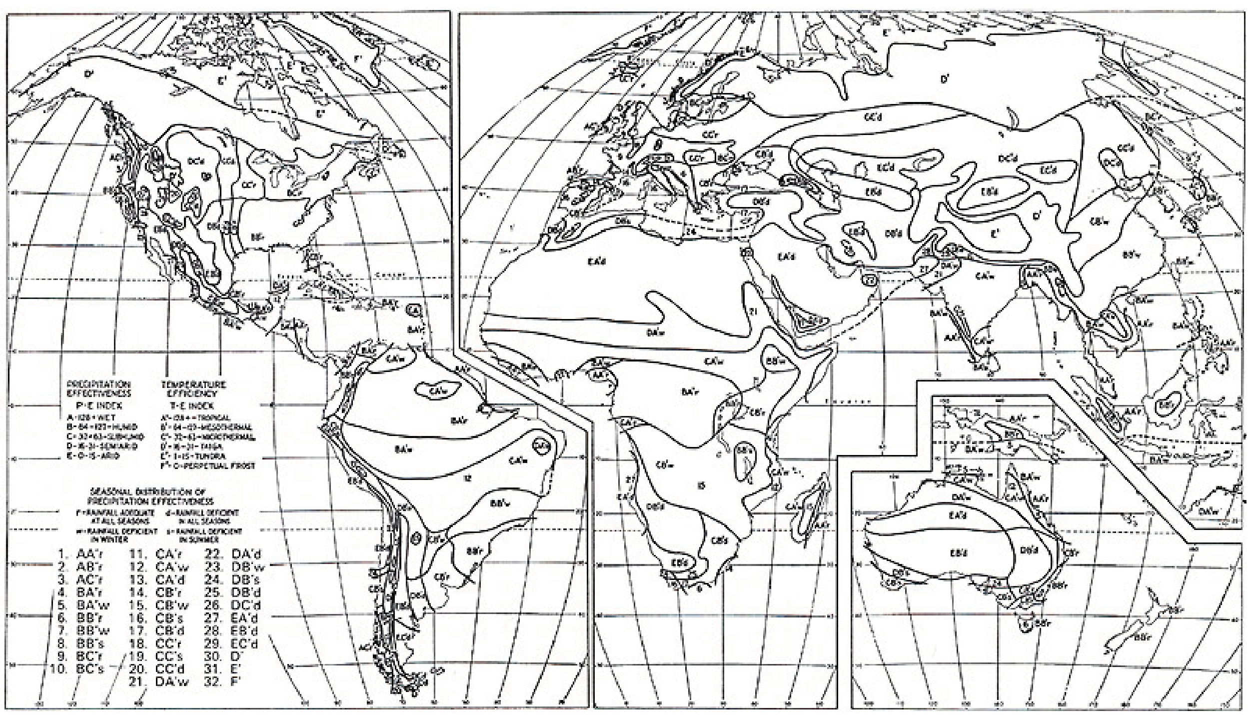


Fig. 2. Temperature and humidity provences, based on natural vegetation.
[After C.W. Thornthwaite, Geographical Review 21:649, 1931.]

Fig. 3. Climates of the earth.
[From G.T. Trewartha, An introduction to Climate, McGraw-Hill, 1954.]



ent meanings for crops. For example, the purposeful introduction of exotic species by people is quite a different matter from the natural development of floras by migrations that occur over tens of thousands of years. There is, however, a remarkable coincidence between the occurrence of certain types of natural vegetation throughout the world and the occurrence of agricultural regions (Fig. 4). The principal factors that influence the geographical distribution of crops are discussed in the following sections.

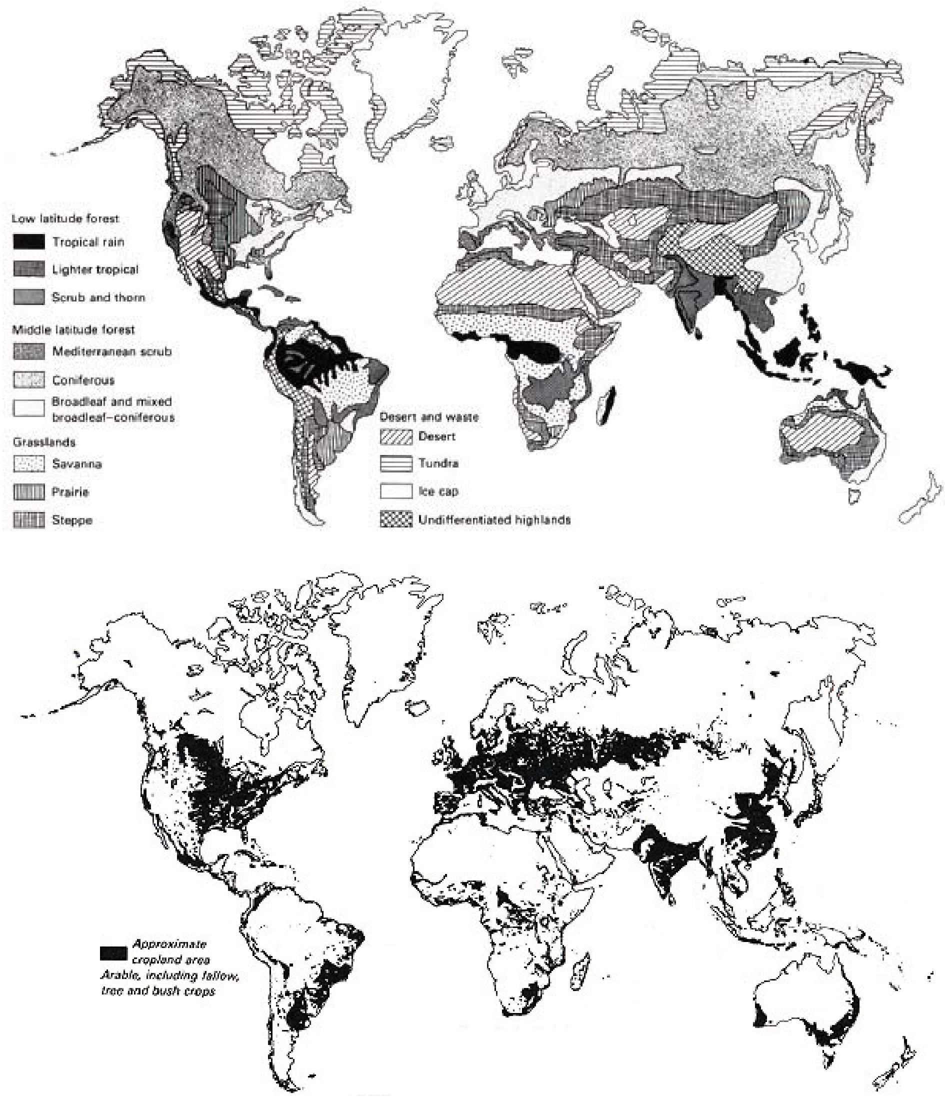


Fig. 4. Natural vegetation of the world (top) compared with approximate cropland area (bottom). [From A Graphic Summary of World Agriculture (USDA Miscellaneous Publication 705), 1964.]

Climatic Control

Plant geographers have always acknowledged the relation between the climate of a region and its natural vegetation. Climatic zonation coincides in a broad and general way with **climax vegetation**, the ultimate type that can develop under a particular local pattern of soil parent material, topography, temperature, precipitation, and other meteorological conditions. As a result, natural vegetation has been used as a kind of meteorological “instrument” to define boundaries in the classification of climate, with the result that savannah, steppe, and rainforest are names for climates as well as vegetation types. Climate is also a primary controlling factor in the growth of crops. The effects of climate on crops can, of course, be altered. Inadequate or excessive moisture may be compensated for by irrigation or drainage. Low fertility may be overcome through the application of fertilizers. In greenhouse production practically all climatic influences can be modified. But fertilization, irrigation, and other cultural practices can be used only to the extent that they yield sufficient return to the grower. It is expensive to modify natural climatic influences.

Reading 4

In 1840 Justus Liebig formulated a hypothesis that plant growth is limited by the nutrient available to it in least quantity. This concept, now popularly known as the **law of limiting factors**, can be expanded to include all environmental factors that contribute to growth. It implies that growth, like a chain with its proverbial weakest link, is limited by the factor that is least favorable. However, all sorts of interactions and compensations come into play with environmental factors.

Although plant growth is affected by subtle differences in climate, the extremes produce the greatest effects. Thus, the climatic extremes of a particular region may be more important in maintaining a vegetation type than the average. An occasional severe period of drought may preclude the development of forest vegetation even though the average annual precipitation is adequate. Cotton cannot be grown in regions that have heavy rainfall during boll formation, even though the climate may be otherwise suitable. Climatic extremes have great influence on the distribution of such perennial crops as fruits (Table 1). Although citrus can be grown in northern Florida and southern Alabama, the hard freeze that can be expected every few years precludes the establishment of an industry in these areas. Some tropical crops, such as cacao and bananas, are injured by low temperatures above freezing. The relation between temperature and the growth of temperate-zone crops may be quite complex. For example, areas of peach culture are bracketed by high and low temperature requirements. Low temperature is required for dormancy, but injury follows extremely low winter temperatures, and the flowering stage is very sensitive to frost. Relatively high temperatures are required during the growing season.

The boundaries of agricultural regions are determined by climatic factors. In the Northern Hemisphere the limits are determined by low rainfall and low temperature. In Africa low rainfall

Table 1. Classification of common fruit crops by temperature requirements.[1]

		Temperate	
Tropical	Subtropical	Mild winter	Severe winter
coconut		almond	
banana		blackberry	
cacao		grape (European)	
mango		persimmon (Japanese)	
pineapple		quince	
papaya		peach	
coffee		cherry	
date		apricot (blossoms tender)	
fig		strawberry (very hardy with snow cover)	
avocado		blueberry (very hardy with snow cover)	
	citrus	raspberry	
	olive	cranberry	
	pomegranate		pear
			plum
			grape (American)
Sensitive to low temperatures	Slightly frost tolerant	Tender	Winter-hardy
Not cold requiring		Cold requiring	

[1]Variation in tolerance depends to a large extent on species, variety, plant part, and stage of growth.

is limiting both in the south and in the north. In South America the boundaries are set by low temperatures in the south, the harsh conditions of high altitudes and poor soil near the equator, and low rainfall in the northeast and along parts of the Pacific coast. In Australia intensive production is confined to coastal areas that have adequate rainfall.

The action of any single environmental factor is affected by all other environmental factors; that is, the environment is **holocoenotic**. The physiological responses of plants are conditioned by the collective action of the environment.

The stress that one environmental factor imposes can sometimes be relieved by making another factor more favorable. For example, the debilitating effects of drought may be somewhat less severe in crops that were well fertilized before the drought began.

Opposite climatic types may be compensatory. In the far north, long days may partially compensate for short growing seasons and permit the cultivation of field crops that otherwise could not be grown. In the western United States, roughly 100 to 150 centimeters (about 45 to 60 inches) of precipitation is required for the development of mature forest vegetation, including such species as Douglas fir. Yet this species grows well in England, where precipitation may be only 60-100 centimeters (about 25-40 inches), but where heavy mists and fogs reduce transpiration.

The compensation of one environmental factor for another is most common near the edge of a species' range. For example, spruce (*Picea*) and fir (*Abies*) grow in the cooler climates of high latitudes, but both kinds of trees grow at high elevations far south of the region of their best development. Thus elevation compensates for latitude. In the southern United States, eastern white pine (*Pinus strobus*) is frequently found at low elevations far south of regions in which it might be expected on the basis of its temperature requirements, but it is always found in coves or on slopes that are sheltered by natural topographic features. Topography can therefore compensate, to some extent, for latitude.

Climate exerts a major influence on natural vegetation through its effect on soil development. Natural vegetation progresses through successional stages in concert with the development of the soil. If climatic elements or the parent material are adverse to either the physical or the biological processes of soil formation, there can be no progress to more advanced stages.

Soil may become the limiting factor for some species even when all other climatic factors are favorable. For example, soils composed mainly of quartz sand, which is extremely resistant to weathering, can never develop into deep, rich soils such as those in regions where limestone is the parent material. Limestone is dissolved by carbonic acid, which is a natural component of rainwater and also forms from decomposition of organic matter. Some species of trees require deep soils that allow the development of extensive root systems. Sandy soils may not have enough water-holding capacity for the production of some crops, even though rainfall is abundant. Conversely, if the water table is too high, normal root development may be restricted. Soils that hold water on the surface make good rice fields but will not support corn. In some soils a deficiency or excess of minerals can be the limiting factor. Nevertheless, soil must be considered of secondary importance in controlling the distribution of crops. If soil conditions are not extreme they can often be altered to render the soil productive. If the demand for a particular crop warrants the expense, the soil may be physically and chemically altered. Fertilization, irrigation, subsoiling, drainage, and fumigation are the most common means used to alter soils.

Environmental Gradients

Environmental factors vary along gradients from one area or region to another. Probably the most extreme example of an environmental gradient is the change in temperature from the equator to the poles. Striking temperature gradients commonly occur where topography causes cold air to drain from smooth, gentle slopes and accumulate at the bottom. Temperature, humidity, and precipitation also vary with distance from bodies of water. Precipitation declines from 115 centimeters (about 45 inches) or more per year in the deciduous forests of the eastern United States to less than 25 centimeters (about 10 inches) on the Great Plains.

Environmental gradients are usually not steep except where topography or some other factor intensifies them. The temperature gradient from the coast to the Piedmont in the southeastern United States is very gradual. Similarly, the precipitation gradient between the deciduous forest and the Great Plains is gentle. Soil moisture shows steeper gradients, for even within a few meters moisture conditions may change greatly. The sharp changes in environmental conditions where topography is irregular are troublesome for crop producers, who frequently wish to establish large production units that are managed uniformly. Large-scale agriculture is difficult in mountainous areas.

The environment is constantly changing, although the changes occur only very gradually. The Wisconsin glacial stage, the most recent advance of the ice sheet that once covered a large part of North America, ended about 12 thousand years ago. The climate has since shown a warming trend, and the extent of glacial ice in high mountain valleys has been observed to decrease markedly during the past 50 years. Other major climatic changes have resulted in a change in vegetation from spruce and fir to such plants as oak, hickory, and grasses, which can tolerate drier climates.

Because climatic change is gradual, many crop growers would maintain that it is not realistic to take it into account, but within the large climatic changes and cycles there are smaller changes that can be witnessed within a generation. For example, the United States National Weather Service has abandoned the practice of using the total weather records available for a station to determine mean and average values, and now uses a shorter period of time, 25 to 30 years. However, in the tropics, an even shorter period may be used because of the more nearly constant weather conditions.

Although environmental changes are gradual, there is often a lag in the kinds of natural vegetation that occupy an area. Plant migration does not always immediately follow site availability. This means that some species may be successfully introduced into regions in which they are not native because the rate of migration has not kept apace of climatic change. Slash pine (*Pinus eliottii*), native to Florida and the Gulf coast, is a notable example; this species has been planted as far north as North Carolina, where it is sufficiently productive to justify planting for timber.

Species Range and Tolerance

The **tolerance** of a species is represented by the range of climatic and soil conditions within which it can exist and reproduce. The expression ecological **amplitude** is sometimes used to describe this range of conditions. There is great variation in tolerance. Some species can exist only in a very narrow range, whereas others can tolerate a broad spectrum of environmental conditions.

In the ecological literature many theories of tolerance have been proposed. Most are concerned with the historical development of natural vegetation and the function that time has served. V.E. Shelford's generalized law of tolerance is of great interest and value to ecologists and geographers, and is defined in terms applicable to crops. Shelford's concepts can be stated as follows:

1. Species with a wide range of tolerance are likely to be widely distributed.
2. Some species may have a wide range of tolerance for one environmental factor and a nar-

row range for another.

3. When one environmental factor is limiting, the range of tolerance to other factors is likely to be decreased.
4. The range of tolerance is likely to be narrowest during the period of reproduction.

Tolerance has a genetic base. Environment can influence the growth and development of organisms only within genetically imposed limits. Species with a wide range of genetic diversity are more likely to respond favorably to new and changed environments than to those with a narrow genetic base. The evolutionary forces that determine the range of species involve differentiation and speciation. Long-term forces apply only incidentally to crop plants, because people have imposed evolutionary change through artificial hybridization and other kinds of genetic manipulation. Adaptability becomes one of the main goals of modern plant breeding. The relatively slow migration of natural species, hampered in many cases by natural topographical barriers, has given way to widespread and rapid introduction of exotic species.

Plants in different stages of growth may have different tolerances. Plants, like other organisms, change in structure as they develop. The developmental phases respond differently to environmental factors. The limits of tolerance are often narrow in the seedling and juvenile stage. For example, the stem of a newly generated long leaf pine seedling has no protective bark and may be killed quickly by temperatures of 60°C (140°F) or less. The same tree, when 10 years old or more, may tolerate temperatures approaching the boiling point for a few minutes, because by that time a thick layer of bark will have developed. Tobacco plants must be protected when young, but after a few weeks they grow well under field conditions. As a seedling, the roots of baldcypress (*Taxodium distichum*) must not be submerged, but later in its life the water level of the habitat in which it grows is often up to the trunk.

In practically all crops, the range of tolerance during the flowering period is relatively limited. Excessively hot dry weather during flowering of corn can cause crop failure if pollen is released before silking occurs, and it can even kill pollen. Similarly, cold wet weather during apple bloom adversely affects pollination because bee activity is reduced.

Because the geographic ranges of species are tolerance-limited, much effort has gone into a worldwide search for areas with similar climates in order to weigh the prospects of successfully introducing crop species from one area to another. Areas with similar climates are called **homoclimes**, or with reference to agricultural production, **agroclimatic analogues**. The crop ecologist M.Y. Nuttonson has studied agroclimatic analogues of the United States using mean temperatures, dates of killing frost, average precipitation, precipitation effectiveness, and other types of climatological data. Beer Menuha, Israel, and Calexico, California, were found to have comparable climates, and are nearly thermal equivalents. Irrigated barley is the most important cereal crop in Calexico because it tolerates soil salinity and grows under a wide variety of soil conditions. Since the same conditions prevail in Beer Menuha, barley might be expected to grow profitably there if equivalent cultural techniques are used.

Biotic Factors

The members of the biologic community, in their roles as parasite, predator, symbiont, competitor, or vector of pollination and propagation, strongly influence the distribution of natural plant communities. Consider the role of the vast herds of animals in helping to maintain the great South African veldt.

Biological factors also have great significance on the distribution of crops. The crop producer works in situations in which the natural biological equilibria are disturbed. Under these conditions the biotic factors of greatest concern are populations of crop pests. The inability of the crop producer to exert sufficient control over a predator or disease can virtually eliminate a crop species. Thus Panama disease has eliminated commercial banana production from large areas of Central America. A number of diseases of the *Hevea* rubber tree have had a great effect in moving the industry from the native habitat of *Hevea* in Brazil to Southeast Asia. The bacterial disease fire blight has eliminated commercial pear production in most of the warm humid areas of the United States.

Crop pests are frequently controlled directly by chemical or other cultural means. Control through genetic manipulation of the crop plants is also widely used to produce new varieties with genetic resistance. The adversaries are often biologically resourceful, however, and the occurrence of new races of some pests has made the incorporation of genetic resistance only a temporary stopgap technique. **Biological control**, the manipulation of biotic factors in the control of plant and animal pests, has recently received a great deal of attention.

Other biotic factors have influenced crop distribution. Many crops depend on biological vectors for pollination. The production of smyrna fig in California was unsuccessful until the *Blastophaga* wasp was introduced for pollination. The value of many legumes as crops depends on their association with particular nitrogen-fixing bacteria. Many legumes proved ineffectual in tropical areas until specific forms of bacterial symbionts were introduced.

Introduction and Adaptation

The term "natural migration" infers that a species has been transported to a new area without human assistance, become established, and by successfully reproducing has become a permanent part of the natural flora. This process is slow and evolutionary. In contrast, the successful dispersal of crop plants, which leads to the permanent incorporation of a particular species into the agriculture of an area, can be a rapid, explosive, revolutionary process.

The dispersal of crop plants typically results from deliberate importation. The widespread dispersal of plant species from the Old and New Worlds during the Age of Exploration took place within a century. At present, plant expeditions to uncover new crop plants and new forms of old ones is a continuing endeavor.

Introduced crop plants do not necessarily have to be able to reproduce in the new area. Many crop industries depend on seed produced outside the area in which the crop is produced. This is often true of plants grown for some part other than the fruit.

Low tolerance in critical periods may be compensated for by cultural practices. The adaptability of crop plants depends heavily on people; most of our crops could not survive on their own in most locations. Corn does not live anywhere except as a crop plant.

Finally, adaptability is encouraged through genetic manipulation. For example, for a long time cabbage would not reproduce itself in the subtropical climate of Brazil, and seed had to be imported each year. But recently in an abandoned field in the state of Sao Paulo, some variants responded to slight chilling and flowered. Selection soon produced types adapted to local seed production, called *repolho loco*, or "crazy cabbage." The tomato is constantly being altered by breeding to maintain adaptability to new locations (it is grown from the equator to as far north as Fort Norman, Canada, at 65º north latitude), to resist local pests, and to adapt to new systems of management such as mechanical harvesting. New strains of wheat must be continually produced to compensate for mutations that occur in the stem-rust fungus (*Puccinia graminis*), a destructive pest of wheat.

In some crop plants it is desirable to prevent change in genetic structure. When crops are particularly adapted to human needs, and where asexual propagation is possible, particular genotypes may be kept intact for long periods of time. The 'Bartlett' pear, the main variety grown in the United States, Canada, and France, originated in England before 1770.

The accidental introduction of destructive weeds has been costly to crop growers. Russian thistle (*Salsola kali*), Japanese honeysuckle (*Lonicera japonica*), and witchweed (*Striga asiatica*) are examples. The migration of fungi and bacteria also causes serious problems. Fifty years after the fungus *Endothia parasitica*, which causes chestnut blight, was introduced to the New York Botanical Garden on an imported chestnut, it had virtually eliminated the native chestnut from the eastern United States. Governmental agencies maintain large and costly systems of quarantine and inspection in an attempt to prevent the introduction of unwanted species. In the United States even individual states have also found it necessary to maintain inspection stations at their borders.

Economic and Cultural Factors

Crops are a part of human economic and social life. The distribution of crop plants is thus affected by many factors in addition to biological ones. The agriculture of any nation strongly reflects that nation's level of economic development and its standard of living. On a local level, such factors as land costs, availability of labor, distance to market, and transportation facilities frequently override biological considerations of climate and soil suitability. Finally, governmental policy in the form of taxes, subsidies, and tariff barriers become important considerations. Even though a crop may be well adapted to a particular climatic regime, there must be a demand for it by consumers and a profit incentive for producers. Countries in which agriculture is organized in such a manner that production incentives are dampened by collective farming or by absentee landlord systems, for example, have found it extremely difficult to achieve rapid growth in agricultural production.

The preferences of people in particular countries and regions for certain kinds of agricultural products has developed over countless generations. Rice is the staple carbohydrate in the Far East; wheat occupies this niche in the West. It would be difficult to reverse the use of these products even if such a change were technologically desirable. Food habits often reflect religious attitudes. Observant Hindus refrain from eating beef, even though India probably has the largest population of cattle of any country in the world. Although preferences are frequently dictated by local productive potential and capacity, they develop into habits or biases that are difficult to change rapidly. Human mobility has increased greatly in the past several decades, resulting in the introduction of new foods and other plant products, but for most of the world's peoples significant dietary changes are unlikely.

THE FUTURE

Agriculture occupies more people than any other trade in the world. Even so, only 8 to 9% of the total land surface of the earth is under cultivation–approximately 1 to 1.2 billion hectares (2.5 to 3 billion acres). Most of this cultivated land is in the middle latitudes, between 30° and 60° north and south of the equator. Four countries–the United States, the Soviet Union, China, and India have a 4th of this land. The distribution of land that is suitable for cultivation is primarily determined by the nature of the physical environment–climate, soil, and land forms.

Vast portions of the earth do not now meet the requirements for crop production. In addition, probably no more than 1/2 to 2/3 of the available land is used for agriculture during any 1 year.

Although no one knows how much more cropland can be added to that already under cultivation, there is widespread agreement that we have not yet reached the limit. But practically all of the best land is now under cultivation. Advances in agricultural technology are required to make profitable use of the great areas in the tropics and in the deserts that are now agriculturally unproductive. The expansion of the frontiers of present-day agriculture will be more than a challenge for future scientific pioneers.

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